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SHRINKAGE OF CONCRETE DUE TO CHANGE IN TEMPERATURE AND MOISTURE CONTENT

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BY

ILMAR OSCAR JAHLSTROM

B. S. State College of Washington, 1923

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING IN THE GRADUATE SCHOOL OF THE UNIVERSITY OF ILLINOIS, 1925

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I. INTRODUCTION.

1. Preliminary

The use of concrete has grown to such an extent in recent years that a better knowledge of its behavior under temperature and moisture changes is needed.

Concrete, like steel, expands and contracts with changes in temperature. The thermal coefficient of steel is practically uniform, while that of concrete varies with the richness of the mixture.

Investigations show that concrete contracts when there is a loss in moisture, and expands when there is an absorption of moisture. This phenomenon of concrete deforming under different conditions of moisture content is of great importance in large concrete structures, such as arches. What stresses this deformation of the concrete due to moisture changes produces in an arch, for example, is not known at present.

At present investigations are being made to study the effect of moisture content on concrete. With more information in regard to changes produced in concrete due to temperature and moisture variations, valuable data useful in the design of concrete structures will be added to the present meagre knowledge.

A. HISTORICAL SURVEY OF PREVIOUS OBSERVATIONS

In the following pages a brief summary of the observations made on the contraction and expansion of concrete due to varying moisture content will be given.

Articles by the authors referred to can be found in the bibliography.

J. R. Emerson

One of the earliest experiments along this line was made jointly by Emerson and Pumpey, students at the Ohio School of Applied Science. Although their experiments were not on a large scale they showed qualitatively the action of concrete when immersed in water and when dried in air. They found that concrete in water expanded and contracted when exposed to air.

In these tests as in almost all the following, the sizes of the specimens were small. Emerson used specimens 7 in. by 2 in. by 30 in. in size.

A. R. Binney

A. R. Binney made observations on the effect of temperature on a block of granite concrete 100 ft. long and one foot square in cross section. It was built to rest on rollers and free to expand in all directions. Movement of the block was measured by pointers attached to the ends and moving against pillars detached from the block itself. Readings were taken over a period of three years. It was noted that the expansion and contraction of the concrete was greatly influenced by the condition

of the atmosphere, in wet weather the expansion due to absorption of moisture was often as much as that due to summer heat. Taking the average of all conditions in various states of weather, the expansion was: 0.00023 inch for a rise in temperature of 1° F. for a block 100 ft. long and 1 ft. square.

To observe the absorption of moisture by concrete, a cube of concrete 1 ft. on a side was suspended from a steel-yard projecting through the wall of a small building, exposing its 6 sq. ft. to the weather. In 24 hours a gain in weight of 2 lbs. was noted.

A. H. Hain

His tests were made on rather small specimens. The tests included observations on neat cement and on mortar.

The neat cement bars 1 in. by 1 in. by 4 in. in size were dried in a room at about the same temperature for 4 years. One third the shrinkage occurred in the first week, more than one half in the first month and almost all in the first year. A total shrinkage of 0.088 percent was noted in 4 years, of which 84.0 percent occurred in the first year. Shrinkage at the end of two years was practically the same for aged and fresh cement.

Neat cement bars kept in water at a constant temperature for almost three years showed an expansion of 0.07 - 0.10 percent at the end of the first year and slight expansion from then on. Natural rock cement showed an expansion of 0.10 percent.

The bars were then dried in air at room temperature for 60 days. The largest contraction shown was 0.10 percent and the smallest 0.11 percent. Three and of the four specimens contracted

further than to the initial volume. When again placed in water the expansion was rapid, in one day 90 percent of the length, lost in contraction in 69 days drying, was recovered and expansion slowly continued until three of the four were longer than in the previous immersion. Bars which had shown almost no change under water from the first to the third year, dried out at a rate of 1.7 in. per 100 ft. in air and in one day, when brought in contact with water, again expanded 1.8 in. per 100 ft.

Tests were also made on a 1:3 mortar made of standard Ottawa sand. Eight bars of the same size as the others were used. Bars kept continually in water expanded during the first few weeks as much as .05 per cent; they contracted later and usually expanded again, the final expansion being not greater than .05 per cent. Bars kept continually in air showed greater volume changes than those kept in water, the contraction after three months averaging about 0.08 percent and up to 0.10 percent. When the bars were changed from the dry state to a wet state and vice versa, the change in length was about 0.06 percent. The use of water proofing compound showed no favorable action when tried out. A compound bar composed of one layer of neat cement and one layer of 1:3 mortar expanded and contracted together but at different rates and degrees; the differential expansion varied from 00 - 0.15 percent.

A. T. Goldbeck

These tests were made by the Bureau of Public Roads, U. S. Department of Agriculture to determine effect of moisture on concrete.

Two proportions of concrete were used, a 1:2:4 mix and a 1:3:6 mix, of very wet and very dry consistencies. Plain and reinforced specimens were tested. The percentage of steel used was 0.61. The specimens were 6 in. by 6 in. in cross section and 6 ft. long.

The specimens were cured in air and in water. Corrections were made for temperature differences. From these tests the following conclusions were drawn. A 1:3:4 mixture contracts more than a 1:2:3 mixture, and that the greater portion of the contraction takes place during the first three months and fully 50 percent in the first month. The maximum contraction in six months is 0.00060 inch per inch of length in 1:2:4 concrete. The maximum contraction for reinforced concrete was 0.0035 inch per inch of length. The specimen under water expanded in three months approximately 0.0001 inch per inch of length, xxxxxxxxxxthe volume after one month remaining practically constant.

G. H. Nichols and C. E. McCullough

Nichols and McCullough made observations on the temperature changes in two arches. In connection with these a test block of concrete 12 in. by 6 in. by 36 in. was made to determine shrinkage of the concrete as used in the arch. A 1:2:4 mix was used. The test block was kept at a constant temperature of 72° F. for 100 days, in which time it showed a shrinkage of 0.04 percent

A. R. McMillan

McMillan made tests on shrinkage and time effects in reinforced concrete. The results of his tests on shrinkage only

will be given here. A beam 4 in. by 4 in. by 48 in. exposed to air after the first day showed extremely rapid shrinkage during the first month. A slight expansion in the summer was noted when moist air from the outside was allowed to enter the room. In winter shrinkage again succeeded due to the dry air of the room and during the eleventh month showed a rapid rise. In one year the shrinkage was nearly 0.0008 inch per inch.

Observations were then made on 3 beams 4 in. by 5 in. by 48 in., of 1:2:4 limestone concrete with 0.5 percent reinforcement. The beams were cured alike under wet mats for 3 days, after which one was left open to the air, one kept 12 weeks under wet mats, and the other alternately covered and open. The beams were kept in such a way that no other influence except difference of moisture content was present. It was found from these tests that the total shrinkage was independent of the condition of curing; the specimens all being almost dry at the sixth month.

Tests made on cylinders gave similarly except that they are not re-wetted at the 100th day [illegible] showed the following results.

Av. two cyl. exposed continually to dry air	1710 lb. per sq. in.
Av. two cyl. alt. wet and dry	1515 lb. per sq. in.
Av. two cyl. [illegible]	[illegible] lb. per sq. in.

Conclusions arrived at as a result of these tests:

With materials and mixtures as used in these tests, it is safe to predict a shrinkage of from 3 to 1 [illegible] or more in 100 ft. when exposed to the ordinary dry air of a heated building.

It is not certain when shrinkage will cease, however ½ to 2/3 of the shrinkage may be expected within 40 to 60 days after exposure to dry air. Curing concrete in a moist medium during the early stages seems to have no effect in reducing total shrinkage, the only effect being to retard the action; this in spite of the fact that the strength of the concrete is materially increased by the treatment.

Slight increases in moisture content will retard shrinkage and even cause swelling, which seems to warrant the belief that structures open to the elements would never show the same total shrinkage found in these tests. Continual shrinkage in beams and slabs acts to produce an increasing deflection, though not to the same extent as time yield.

Torata Matsumoto

Tests by Matsumoto at the University of Illinois on plain and reinforced concrete substantiate earlier tests.

Observations on 30 specimens 2 in. by 3 in. by 24 in. in size, mortar and plain concrete, exposed to damp storage, dry room air and finally oven heat, showed that richer mixtures absorb more water and expand more than leaner ones, shrinkage is greater for mortars and rich concretes than leaner concretes. It was noted in the case of a 1:1 mortar that it contracted 0.025 percent in 70 days although it contained more moisture than its initial amount. The author concludes that the water which goes into concrete may exist in two different ways, either combined with cement in a chemical compound, or remaining in a state which effects the volume of the concrete. Slight contraction was also noted in concrete in which the moisture content was kept uniform.

In a second set of tests on 24 specimens, half of 1:2 mortar and half 1:2:4 concrete, it was noted that dry concrete

and mortar expand as soon as they absorb water. The rate of absorption upon immersion is much less for older specimens than for new during the first few days, although the total amount of absorption is about the same for specimens of different ages. The ratio of expansion due to immersion is also less for older specimens than for new during the early stage, for longer periods it is about the same. Expansion in mortar is greater than in concrete. The amount of expansion of mortar and concrete is small until an absorption of nearly 3% is reached. The absorption of moisture by mortar or concrete is more rapid than the drying out of moisture from same material. A mortar 7 days old gained as much moisture in 8 hours immersion as could be dried out by heating to 180° F. in an oven for 24 hours.

A test on this same relation of absorption and expansion of concrete was made on two samples of concrete 3 years old. This concrete contracted 0.010 percent after drying 12 days in an oven at a temperature of 180° F; after immersion in water for 12 days, the average absorption was 5.33 percent with an average expansion of 0.048 percent.

Tests of water absorption and expansion were also made on sandstone and limestone. Two sandstone specimens, 3 in. by 4 in. by 24 in. and 3.5 in. by 4 in. by 25 in., in size were observed. After immersion in water for 12 days, the average absorption was 5.76 percent with a corresponding expansion of 0.081 percent. This is much greater than the amount of expansion of concrete for the same period of immersion. The limestone specimen showed no measurable contraction due to drying out and practically no expansion, although the absorption of moisture was 5.16.

The tests included measurements on reinforced concrete specimens, the amount of reinforcing varying from 0.0055 percent to .0654 percent.

As a result of his tests, Matsumoto concluded that: Concrete of a 1:2:4 mixture is likely to contract during hardening as much as 0.05 percent in an ordinary structure.

The shrinkage stress caused in the steel in reinforced concrete may reach the working stress of the steel when the amount of the steel is below 1.5 percent.

The shrinkage stress developed in 1:2:4 concrete may reach the ultimate tensile strength of the concrete when the amount of reinforcement is greater than 1.5 percent. With richer mixtures the increase in shrinkage stress may be relatively greater than the increase in ultimate strength.

E. H. Harder

E.H. Harder gives data obtained from experiments by Bach and Graff Using these data, he points out the fact that the actual deformation measured on a plain concrete specimen was 20 times that obtained from the steel deformation by assuming uniform stress throughout the reinforced specimen. This shows that the deformation is not uniform through a section but is greatest at the edges. He also points out the fact that the usual formulae for getting the stress in the steel and concrete due to shrinkage may be true only for specimens of small cross section, due to the fact that the concrete is assumed uniformly restrained throughout the section, a condition which does not hold in large specimens.

The author made strain gage observations on two of the arches on a reinforced concrete bridge at Fairmont, W. Va. From his observations there he concludes that shrinkage stresses are important, that they vary with location on the arch due to exposure, moisture of cross-beams ~~xxxxxxxxx~~ etc. In two years a deflection of $\frac{3}{8}$" ~~xxx~~ at the crown was observed, which was due to shrinkage of the concrete.

Remarks:

It will be noted that in all the above experiments regarding shrinkage due to moisture content, the size of the specimens was rather small. This allows a rather uniform moisture content throughout the specimens. In concrete structures this condition cannot be approached so that it may be expected that the moisture content and therefore the deformation will vary. It is reasonable to suppose that in large structures exposed to weather the center concrete remains at a practically uniform water content, the exposed portions varying more according to the weather.

Not much attention was given in the previous observations, with the exception of T. Matsuoto's work, to the amount of moisture absorption. Concrete in general practice would not be subject to such immersions or exposures to moisture as in these laboratory tests.

With such small specimen pieces no data was obtained on the relation between the shrinkage and contraction of the exterior region as compared to the interior region of the specimen.

It would be expected that the exterior region would show more deformation, being less restrained in movement than the interior region.

It is interesting to note that A. H. White found in his experiments that bars made of 1:4 mortar after squeezing under water stored in contact after several years immersion and then squeezed again. T. Matsuda observed the same phenomena. He found that a 1:1 mortar had contracted 0.008 percent in 70 days although its moisture content was larger than the initial amount. A slight contraction was also noticed by Matsuda in concrete in which the moisture content was kept uniform.

W. K. Hatt

Professor W. K. Hatt, of the Engineering Experiment Station of Purdue University, has made a study of the effect of moisture on concrete.

His investigation consisted mainly of two parts, (1) observations on a concrete road slab 7 in. thick, 14 ft. wide and 26 ft. long with a dowseled longitudinal joint through the center, (2) tests of strength and length changes of small beams with varying moisture conditions.

The slab was cured under water 30 days and then dried by circulating air above and below the slab. The slab rested on a porous gravel subgrade which could also be saturated with water. After 30 days of drying, the more rapid drying at the top surface warped the slab to a maximum deflection upward of 0.07 in. at the corner and 0.06 in. at the unbroken edge, no further shortening occurred. The diagonals shortened 0.07 percent. After 3 months of further drying, the slab had warped dry thru' joint and substantially level, with a diagonal shortening of 0.0613 percent.

The slab was then subjected to moisture at the bottom. During 110 days of saturation, the slab warped upward 0.40 in. at the corners and 0.383 in. at the unbroken edge, simultaneously a diagonal shortening of 0.0073 percent occurred in the top of the slab, of which 40% took place in 9 hours, and nearly all in 5 days.

A temperature rise of 40° F. warped the corners downward 0.125 in. or 31 percent of the total warping (0.41 in.) at that point.

The investigation included volume changes of concrete and mortars. Small specimens were used for this purpose, 3/4 in.

specimens for the neat cement twin, but varied in the concrete tests.

Measurements were taken 8 days after moulding. The volume changes in the several brands of cement varied greatly. The expansion in water during 13 days was from 0.00 to 0.040 percent. The contraction in air for 90 days subsequent to immersion was 0.054 to 0.198 percent. Gravel concrete of a 1:2:3 1/2 mix while under water 40 days expanded .005 per cent, while in air 90 days contracted .041 percent, and while in an oven it contracted .05. ~~an oven~~. Gravel concrete of a 1:1 1/2:3 mix with a different cement, expanded 0.00 percent in water, contracted 0.11 percent in air, and 0.0[illegible] percent in the oven, during the same periods as before.

It seems that greater value expect that in every case consistently contracted least in air. Neat cement pitted expanded in water 10 times as much as the concrete beams and contracted nearly five times as much as the concrete.

Some important results were also obtained from observations made on a concrete stadium at Purdue University.

Gauge points were placed on the open decks and revetment of the stadium.

A drop in air temperature of 3[illegible]° F. appeared as a drop of 2[illegible]°F. in a parapet wall 3 in. thick, reinforced with [illegible].5 percent reinforcing both ways. The wall is integral with a heavy foundation wall. The thermal coefficient of expansion was 0.[illegible]700 in. per degree F. at the top of the wall and 0.[illegible]5 in. at the base.

The movement across a 12mm crack in the middle of a 40 ft. length of this pavement wall was 0.000471 in. per degree F. and at the bottom across the crack 0.000717 in.

Under a drop of air temperature of 38 degrees F., the drop in the concrete in the open deck portion at the middle was 27 degrees, but of the concrete in the revetment 44 degrees. The coefficient of thermal expansion of the open deck was 0.000059 and of the revetment 0.0000098.

The effects of rainfall, followed by a drop in temperature of 10 degrees F., balanced each other, no change in length being recorded. This corresponds to a thermal coefficient of 0.000000 and a swelling of 0.005 percent.

Some of the conclusions arrived at by Professor T. E. Tatt are:

Saturated concrete has 80-85 percent of the strength of dry concrete.

The thermal coefficient of expansion varies with the temperature and ranges from 0.000060 at 20 degrees to 0.000080 at 140 degrees F.

Measurements begun after the initial hardening of concrete show that concrete may expand 0.01 percent due to absorption of moisture and may contract 0.04 percent when exposed to dry air. These changes continue. To these values should be added the changes in length during initial setting of the concrete.

A combination of shrinkage with drying and a fall in temperature will produce maximum shrinkage stresses. A combination of a drop in temperature and a rainfall may raise the concrete at its previous length.

OBSERVATIONS ON A CONCRETE ARCH AT DANVILLE, ILLINOIS

Professor N. M. Tilson, of the University of Illinois, has been taking extensive observations on a concrete arch bridge at Danville, Illinois. The bridge consists of six arch spans and two approach spans. Strain gauge readings were taken on the second arch span from the north end. The concrete was about years old at the beginning of the observations.

These readings are taken at the haunches, at the crown, and at two points near the crown where the main longitudinal bars begins, a total of five sets of observations. The readings are taken longitudinally in the arch rib, a reading on both the top and bottom of the rib is taken except at the crown where only the bottom is accessible.

This investigation of the deformations produced in a concrete arch due to temperature changes and other causes is probably the most extensive yet undertaken. The investigation includes other observations which need not be discussed here.

Greater care was used in taking these readings than has been done previously in work of this kind. A standard bar of invar steel was enclosed in a wooden box with a thermometer attached. The strain gauge could be conveniently checked at all times and the corresponding temperature of the standard bar noted. The temperature of the concrete was determined from mercury thermometers placed in temperature wells drilled into the arch rib. These temperature wells had an stress in the protected by a cork through which was a hole for insertion of the thermometer.

A 20 in. strain gauge was used in taking the readings.

The observed deformations were plotted with the deformation due to temperature and gas. The thermal coefficient of expansion of concrete was taken as 0.0000055, a value which gives the lowest average value for both top and bottom of the rib. The difference between the temperature and observed deformation is the deformation due to moisture changes and other causes, this curve is plotted on the same sheet.

A study of the curves plotted (see pp. 21 to 25) for each section shows that the temperature and observed readings vary in the same way. The curves agree very closely at times, indicating that during this period practically all of the deformation was due to temperature change alone.

The curve showing deformation due to other causes than temperature changes indicates that the bottom of the arch rib moved continuously from the initial reading, reaching a maximum during the hot summer months. The last reading shows an expansion, being taken in a period of damp weather.

The top of the arch rib shows very little variation either way until readings taken during the fall, when expansion was shown. During the winter months and up to the last reading taken in the spring, expansion is shown.

This difference in the top and bottom deformations of the arch rib due to other than temperature changes, can largely be explained by the fact that be sheltered in better protection from moisture in the form of rain and other precipitation.

The average maximum shrinkage for the five sections due to causes other than temperature is 0.0071 percent.

A noteworthy point is the marked agreement of the curves for the five bearing-wall tests and considerable in the observations.

TABLE 5

VARIOUS COEFFICIENTS OF EXPANSION

OBSERVER	MIX	COEFFICIENT	APPARATUS	REMARKS
W. S. Pence Lehigh Univ.	1-2-4 stone 1-2-4 gravel limestone	.0000065 .0000064 .0000066	telescope arrangement	Specimens 6x6x24 in. " 4 in. diam. x 30 in. long
A. R. Binnie	4-1 granite concrete	.0000066 in. in 100 ft. (.0000044)	vernier arrangement	Block 100 ft. long and 1 ft. square in cross section. Block outdoors. Coeff. is av. of all conditions.
C. L. Norton M. I. T.	1-3-6 stone	.0000055	telescope arrangement	6 and 10 in. cubes
T. Matsumoto U. of Ill.	1:1:3; 1:2:4 1:3:6	.0000055 to .0000065		
W. N. Hatt		.0000040 to .0000060		at 65° and 140° F.
Present test	1:2.8:5.9	.0000052	strain gauge	2 specimens 6 in. in diameter and 24 in. long

TABLE 6

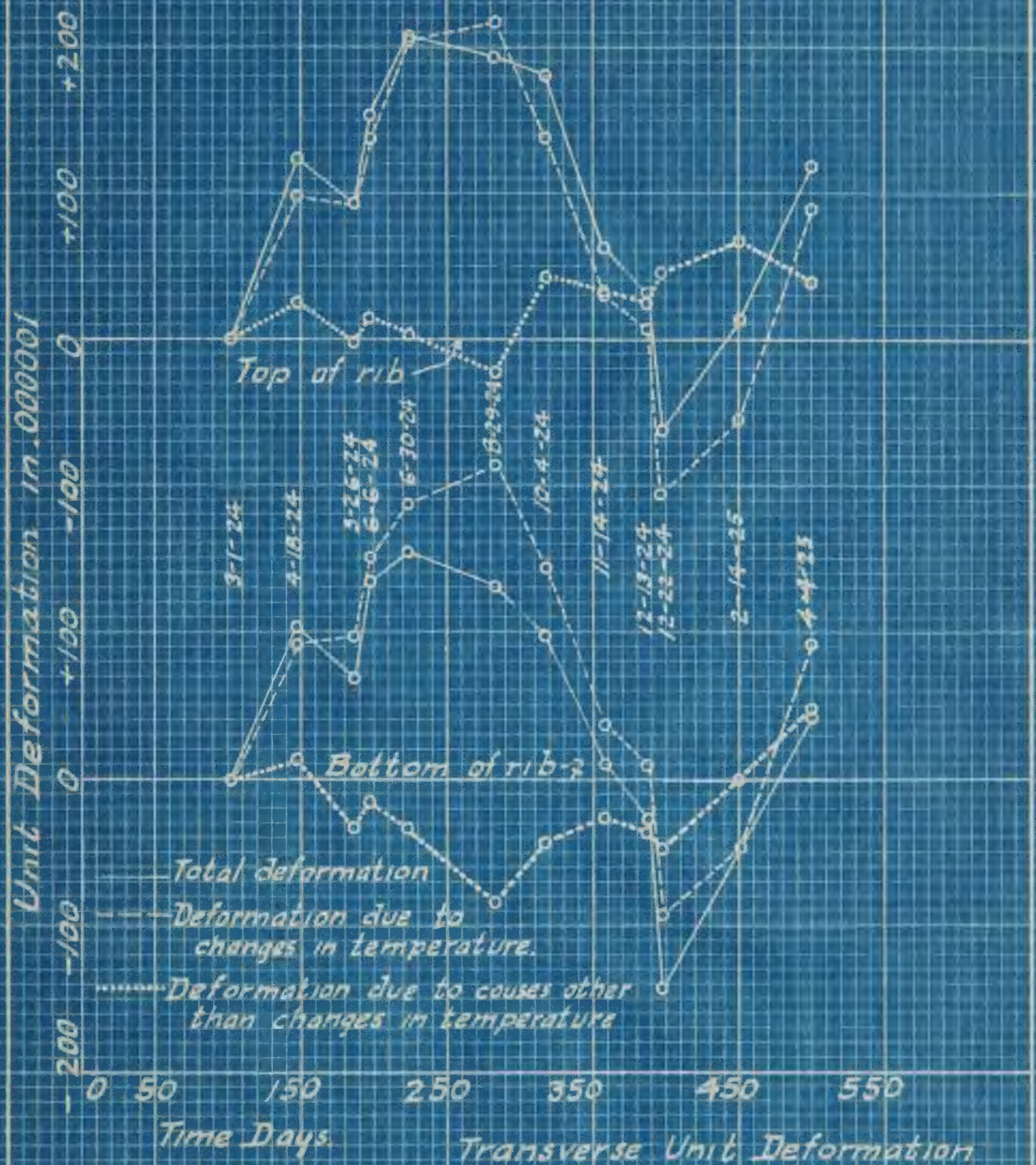
[illegible]

Observer	Mix	Exposure	Age	Coeff.	Remarks
			[illegible]		
Bauschinger	neat cement	under water	14 wks.	+0.066	small cubes, av. of 2
"	1:3 mortar	" "	"	0.070	
"	1:6 "	" "	"	0.071	
Schumann	n.c.	" "	1 yr.	0.150	av. of 7
"	1:3 mortar	" "	1 "	0.022	"
"	"	" "	2 "	0.030	"
"	"	" "	3 "	0.027	"
Tonei	n.c.	" "	90 da.	0.032	av. of 5
"	1:3 mortar	" "	"	0.037	"
Considere	n.c.	" "	63 "	0.079	Spec. 60x25x610 mm.
"	" reinf.	" "	"	0.022	reinf. bar 10.2 mm. in diam.
"	1:3 mortar	" "	"	0.031	
"	" reinf.	" "	"	0.006	
Gary	n.c.	" "	3 mo.	0.078	av. of 10
"	"	" "	1 yr.	0.094	"
"	"	" "	2 "	0.092	"
"	1:3 mortar	" "	3 mo.	0.[illegible]	"
"	"	" "	1 yr.	0.[illegible]	"
"	"	" "	2 "	0.000	"
Campbell & White	n.c.	" "	5 "	0.190	
White	"	" "	1 "	0.07 - 0.15	spec. 4x4x1 in.
"	1:3 mortar	" "	1 "	0.06 - 0.05	"
T. Naimoto	1:1:3 conc.	" "	33 da.	0.0051	percent of gauge length
"	1:2:4 "	" "	"	0.0065	" " "
"	1:3:6 "	" "	"	0.0019	" " "
S. E. Hatt	n.c.	" "	10 da.	0.03 - 0.056	
"	1:2:3 1/2	" "	60 "	0.075	
"	1:1 1/2:3	" "	60 "	0.005	

TABLE 7

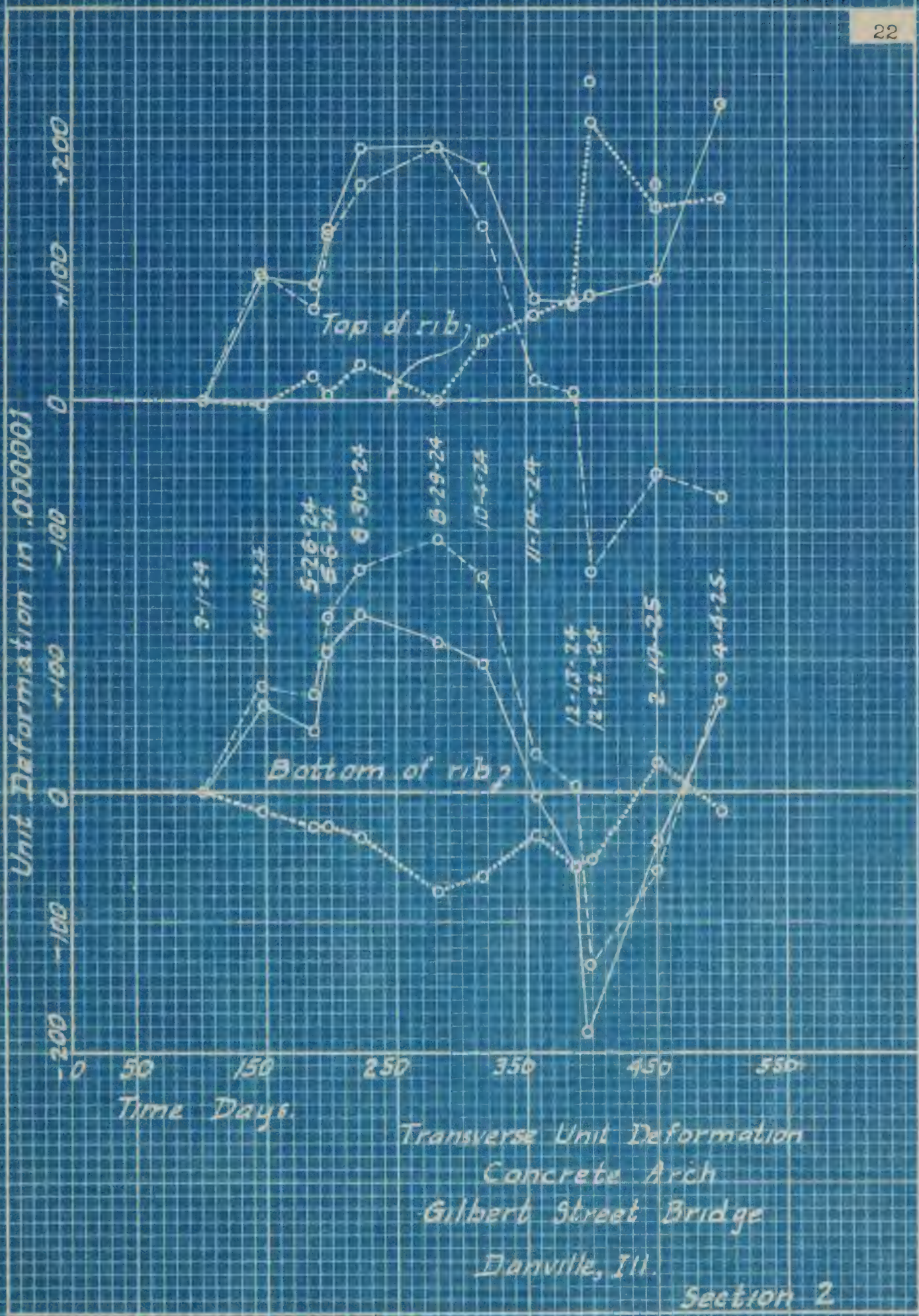
SHRINKAGE CONSTANTS

OBSERVER	MIX	MOISTURE	LENGTH OF EXP.	SHRINK.	REMARKS
Bauschinger	neat cement	cont. in air	16 wks	0.114 %	av. of 8 specimens
"	1:3 mortar	"	"	0.132	
"	1:5 "	"	"	0.134	
Schuman	1:3 "	1 wk. water	3 wk. air	0.041	av. of 4 spec.
Tomei	n.c.	cont. in air	90 da.	0.072	
"	1:3 mortar	"	"	0.094	
Considere	n.c.	"	63 da.	0.111	spec. 70x2x600 mm.
"	" reinf.	"	"	0.022	reinf. bar 10.2 mm. in diam.
"	1:3 mortar	"	"	0.030	
"	" reinf.	"	"	0.010	bar 10.2 mm. in diam.
Campbell & White	n.c.	"	5 yr.	0.200	
White	"	"	3 mo.	0.14 - 0.22	
"	"	"	1 yr.	0.18 - 0.34	
"	1:3 mortar	"		0.06 - 0.09	
L. T. Page	1:2:4 conc.	"	3 mo.	0.060	6 in. sq., 5 ft. long
"	" reinf.	"	3 "	0.030	1/2 in. round bars 1 in. apart
MacMillan	1:2:4	"	1 yr.	0.060	4x8x18 in. 0.25% reinf.
"	" reinf.	"	1 "	0.045	4x8x18 in. 0.34 "
Gray & Lochlitor	1:2:4 stone	"	91 da.	0.035	30x30x4 in. slabs
"	" gravel	"	"	0.040	"
"	1:3:5 stone	"	"	0.030	"
"	" gravel	"	"	0.035	"
T. Matsumoto	1:1:2 conc.	"	50 da.	0.036	percent of gauge length
"	1:2:4 "	"	"	0.033	"
"	1:3:6 "	"	"	0.036	"
S. H. Wilson		outdoors (dry weather)		0.0071	shrinkage on Danville arch. Taken on bottom of rib.
W. K. Hatt	n.c.	air	90 da.	0.088 - 0.142	subsequent to immersion
"	1:2:3 1/2	"	"	0.042	
"	1:1 1/2 :3	"	"	0.015	
Present obs.	1:1.8:3.9	indoors	30 da.	0.0041	max. shrinkage due to other
"	" reinf.	"	30 da.	0.0038	than temp. changes

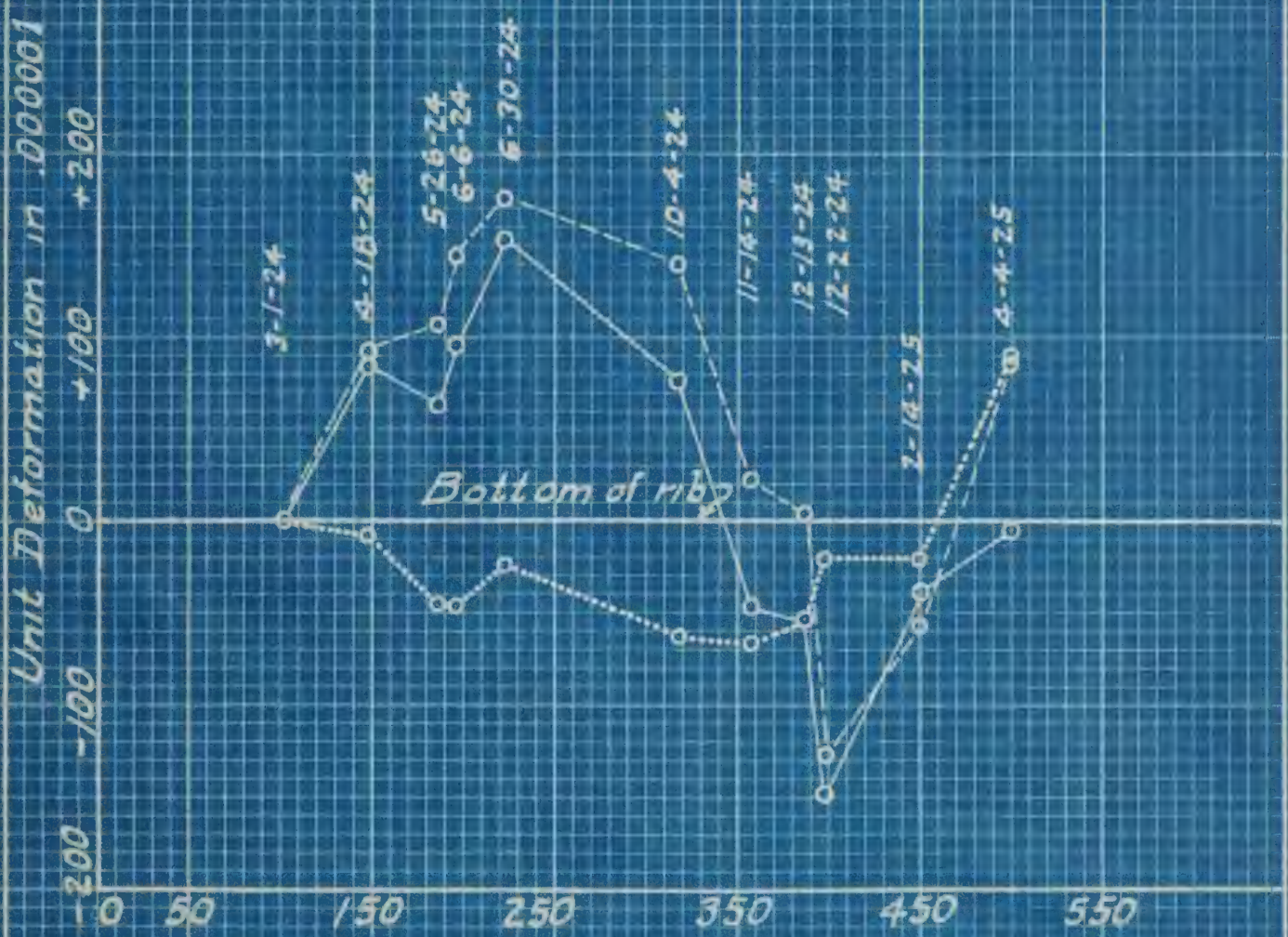


Transverse Unit Deformation
Concrete Arch
Gilbert Street Bridge
Danville, Ill.

Section 1.

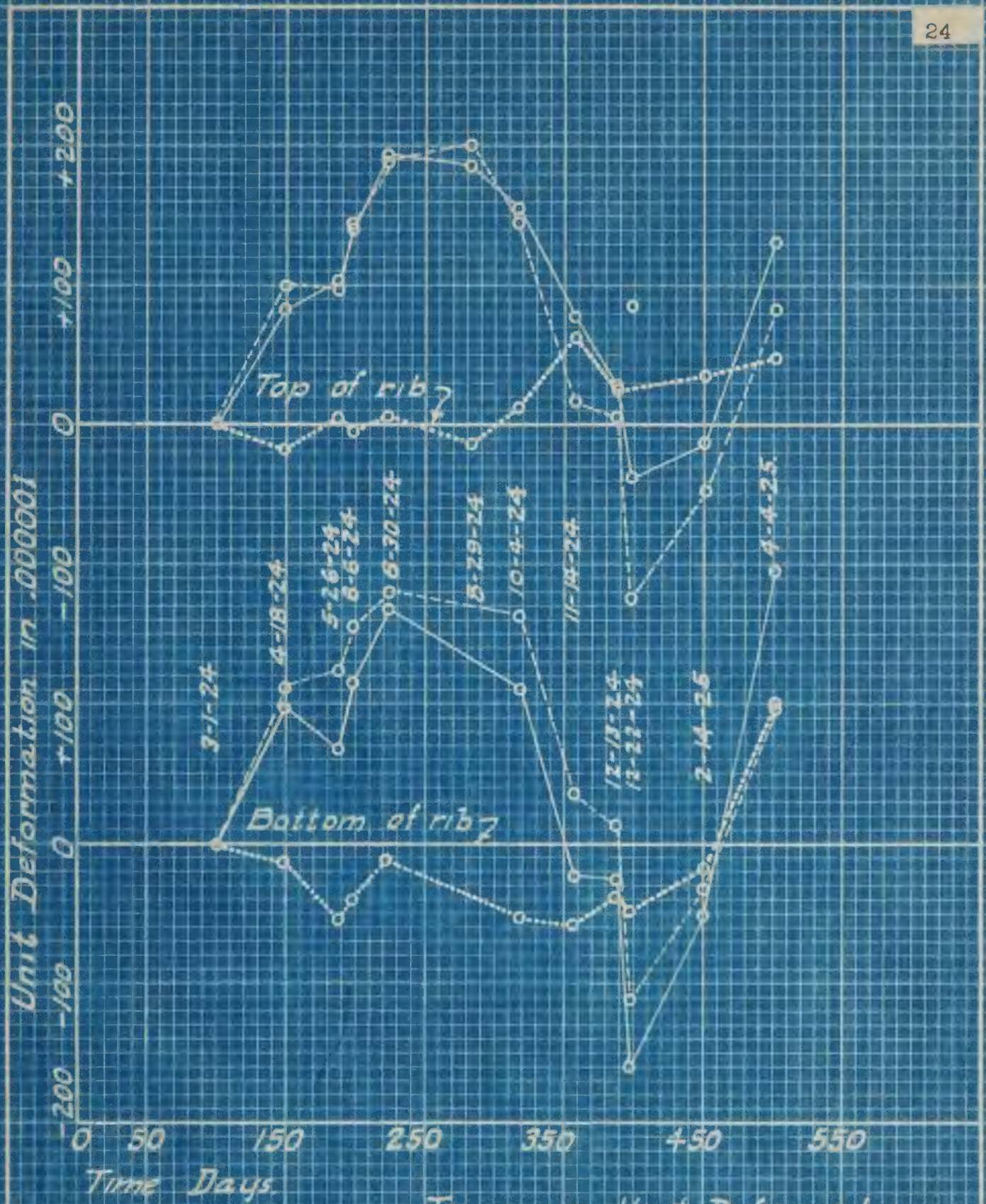


Transverse Unit Deformation
Concrete Arch
Gilbert Street Bridge
Danville, Ill.
Section 2



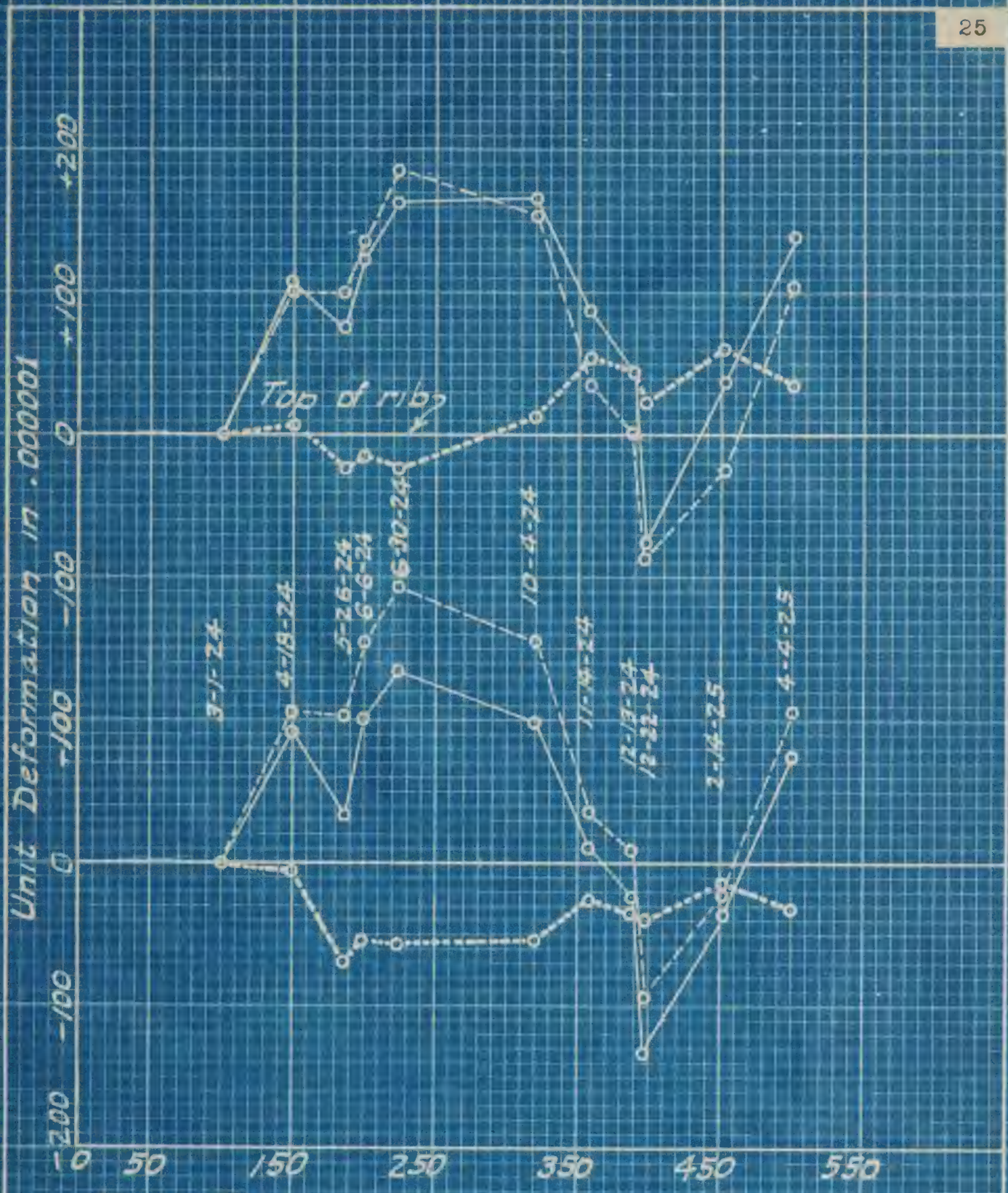
Transverse Unit Deformation
Concrete Arch
Gilbert Street Bridge
Danville, Ill.

Section 3



Transverse Unit Deformation
Concrete Arch
Gilbert Street Bridge
Danville, Illinois

Section 4.



Transverse Unit Deformation
Concrete Arch
Gilbert Street Bridge.
Danville, Illinois

Section 5

3. OBJECT AND SCOPE OF INVESTIGATION

The present investigation was planned to determine more fully the changes which occur in a block of concrete such as may be taken from an area, due to temperature and moisture variations.

It is hoped to get some information as to the relative deformation of concrete near the center of the specimen and of concrete near the edges. The effect of reinforcement in restraining cracks will be studied.

By weighing the specimens when observations are taken, the effect of moisture on the concrete will be determined.

The present investigation is only preliminary to more elaborate tests to follow. With this investigation it is hoped to throw more light on some of the phases of concrete phenomena discussed above, so that a more intelligent attack on the problem can be made.

One specimen of plain concrete and one of reinforced concrete were made. These specimens were 5 ft. 5 in. by 4 ft. 4 in. in cross section and 6 ft. 10 in. in length, a block of concrete which may be considered as representing a section of an arch rib.

To determine the deformation of the specimen at all points, a belt of 50 in. strain gauge lines was established on both sides at the center. In addition four sets of strain gauge lines were drilled into the reinforcing bars top and bottom of the reinforced specimen. The ends of the steel bars are flush with the ends of the specimen. Longitudinal deformations over the entire length of the specimen were measured by means of a special Ivan and a special Ivan dial instrument. Non-corrosive metal plugs inserted in the ends and holes drilled deep into the ends of the

steel bars served as measuring points.

With these gauge lines and overall deformation measurements it is hoped to get information on the behavior which may be expected to occur in large concrete structures subject to temperature and moisture changes.

4. ACKNOWLEDGMENT

This investigation was carried on in the Structural Research Laboratory of the University of Illinois. The work was carried on under the supervision of Professor W. E. Wilson to whom acknowledgment is made for the general plan of the investigation, helpful suggestions and aid. Acknowledgment is made to others who may have assisted in the work at various times.

II MATERIALS, SPECIMENS AND METHOD OF MAKING REMEDIES

1. Materials

Gravel -- The gravel was a well graded gravel from Attica, Indiana, screened to pass through a ¾ in. sieve. Table 1 gives the sieve analysis, an average of three determinations.

Sand -- The sand was a well graded sand from the same locality as the gravel, Attica, Indiana. A colorimetric test made of the sand showed almost a clear supernatant liquid above the sand. A silt test indicated that approximately 1 percent of the sand was of fine material such as clay and silt. Table 1 gives the sieve analysis, an average of three determinations.

Cement -- The cement used was Universal Portland cement of standard quality.

2. Specimens and Their Preparation

Two specimens were planned to be representative of a typical arch section. One specimen was made plain, the other reinforced. The sizes of both specimens are 8 in. x 8 in. by 4 ft. 8 in. by 8 ft. 10 in.

Forms -- The forms were built in sections to facilitate removal and very smooth lap joints were. The bottom was built in three sections to enable the forms to be removed while still supported on blocks. The sections allowed of working at the sides and ends to put a block of several specimens and very good results were obtained.

TABLE 4.

Sieve Analysis of Sand

Av. 3 Determinations

Size of Screen	Percent Retained On	Percent Passing
3	1.8	[illegible]
4	[illegible]	[illegible]
8	30.4	72.[illegible]
14	[illegible]	[illegible]
30	11.8	37.[illegible]
38	11.8	[illegible]
48	12.2	[illegible]
100	5.0	[illegible]
(over 100)	[illegible]	

TABLE 5.

Sieve Analysis of Gravel

Av. of 3 Determinations

Size of Screen Diam. of Opening inches	Percent Retained on	Percent Passing
.748	00	100
[illegible]	[illegible]	[illegible]
.371	[illegible]	62.25
[illegible]	[illegible]	[illegible]
.132	[illegible]	[illegible]
.131	[illegible]	[illegible]
(sieve)	[illegible]	[illegible]

TABLE 6.

Tension Test of Sand

Dry

Briquette	C.O.D	Sand Tested
1		90
2	81	100
3	99	95
Av.	91	95

Wet

Briquette	C.O.D.	Sand Tested
1	105	175
2	120	140
3	110	140
Av.	112	160

Specimens A and B.

Mix and Procedure of Pouring — To be a fairly representative concrete as usually used on hand at this laboratory, a mix of 1-3 ratio of cement to aggregates was chosen. The mix as used consisted of 1 part cement to 2.8 parts sand to 3.9 parts gravel, this always gave the best workable mix of that ratio.

The cement and aggregates were measured in batch mixes of correct size, the portions of the batch being either smooth each time. The water for each batch was weighed on platform scales. The cement, sand and gravel were put in first and the water poured last. The materials were then dried for 15 minutes in a small 1½ cu. ft. capacity electric drum mixer. The mix was stirred continuously at the fixed speed and keeping the materials moist was of only than ordinary concern. Due to the care in measuring the dry materials and water, concrete of uniform consistency was obtained throughout the specimens and in the two separate blocks. The relative moisture of the sand and gravel was kept uniform by mixing the required amount of sand and gravel to a uniform consistency just before each run.

Specimen A

Specimen A was the reinforced specimen and was poured first. Figures 1-5 pages 37 to 41 show the location of the strain gauge lines, also dial lines and the tap centers used.

Floating Steel and Arranging Gauge Lines — The reinforcement in Specimen A consists of 6, 1-inch plain square-rod steel bars, top and bottom. All bars were made flush with the ends of the blocks. To keep the steel in the proper position, small nails

Specimen 9

were driven through the end forms at the correct places and their nail ends projected into the dial gauge holes in the ends of the steel bars. To keep the weight of the concrete from pushing the steel down on the bottom, wood blocks were inserted under the bars at the 1-ft. strain gauge points. After the forms were removed, the blocks were taken out and the steel gauge points exposed. To keep the two steel gauge points exposed, lengths of 1 in. pipe were cut with slots in them to fit over the steel bars. These were left in place and served as holders for wooden plugs placed to prevent excessive moisture from entering at the points. The strain gauge holes in the steel were drilled before the steel was placed in the forms . A number 24 drill was used for all strain gauge holes. Somewhat larger holes were used for the dial points.

Concrete Gauge Points -- For the concrete gauge points, non-corrosive metal plugs, half an inch long were used. These plugs were drilled and the holes countersunk. The plugs were held in place while the concrete was poured by fitting the holes over small brass screws into the forms at the correct position. The plugs were then wired to the forms through small holes drilled for the purpose. This method proved to be unsatisfactory, as the forms had to be removed within a day or two, the plugs pulling out due to insufficient grip. They were then replaced in place with more success.

Temperature Rails -- The temperature rails were formed by placing round steel rods as low to project into the concrete for the required distance. After the forms were removed, nuts with holes for thermometers, one at the top and one at the bottom, were placed

in these walls. The use of the metal was about an inch above the bottom of the hole, the spaces were filled with cup grease by means of an Alemite grease gun. The 4½ in. temperature walls had only one mark. The location of the temperature walls is shown on the figures, page 40.

Specimen B

Concrete Gauge Lines — A different plan of putting in the strain gauge and demountable plugs was used in Specimen B. Holes at the plugs places were bored into the tube and 3/4 in. round steel rods about 4 in. long were inserted through these holes and wired down. These rods, when removed, left a hole about 3 inches deep into which the plugs were grouted. This method proved satisfactory and gave good solid plugs.

Temperature Walls — The temperature walls in Specimen B were made as in Specimen A. Instead of six 4½ in. walls top and bottom, only three top and bottom were made in Specimen B.

3. Conditions of Exposure

Indoors — Specimens A and B were both poured indoors and subject to the temperature and dry air of the structural laboratory for several weeks. From the time of pouring until taken outdoors, we minimized the moisture except that from the air in the laboratory.

Outdoors — Specimen A was taken outdoors when thirty days old and the days later Specimen B was taken out at the age of twenty-one days.

The specimens rest on supports at the north end of the structural laboratory. Here they are exposed to all weather conditions, except the direct rays of the sun, although the sun

strikes the specimens early in the morning and late in the afternoon.

The lower plane of the specimens are about 2 ft. above the ground.

4. Apparatus

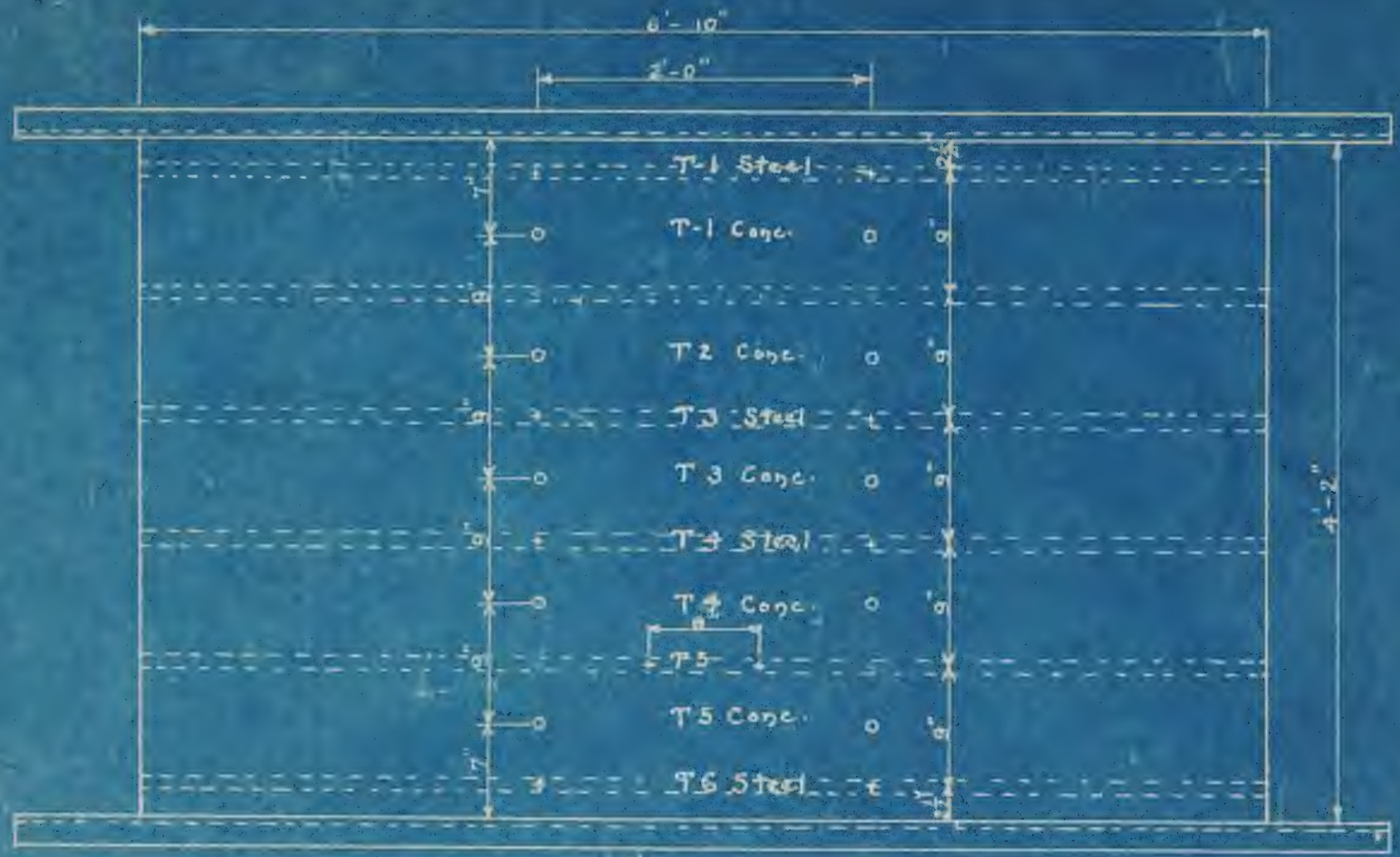
A Berry 50 in. strain gauge is used to take the steel and concrete strain gauge readings, except that an 8 in. Berry strain gauge is used for one steel reading.

The Ames dial readings are taken with a special apparatus (See Fig. 8) Two 2 in. by 2 in. angles on opposite sides of the block parallel with the row of plugs supports a rigid, rectangular frame made of 2 in. by ½ in. flat steel bars. The frame is just wide enough to fit over the specimen and leave space enough at the ends for a special Ames dial gauge. This is an ordinary Ames dial fastened on to a yoke allowing the instrument to be lengthened or shortened as need arises. The plunger of the Ames dial rests against holes directly opposite the plugs, the yoke and rests against bolts in the frame. The frame is kept in a constant position by two screws with conical points which project from the frame and rest in holes in the angles. The screws are both on the same side. Two flat screws on the opposite side of the frame ride the frame on the angles. The frame therefore, is supported at four points.

A circular steel rod pointed at one end to fit the frame gauge holes and having a hole at the other end the head with the Ames dial [illegible] to get the correct length at the frame at each reading of the blocks.

Mercury thermometers were used for getting the temperature of the boxes.

The weights of the specimens were determined by a 2 ton platform scale carried on wheels. This scale was calibrated by standard 25 lb. weights up to 1,000 pounds and found to be accurate within one pound.

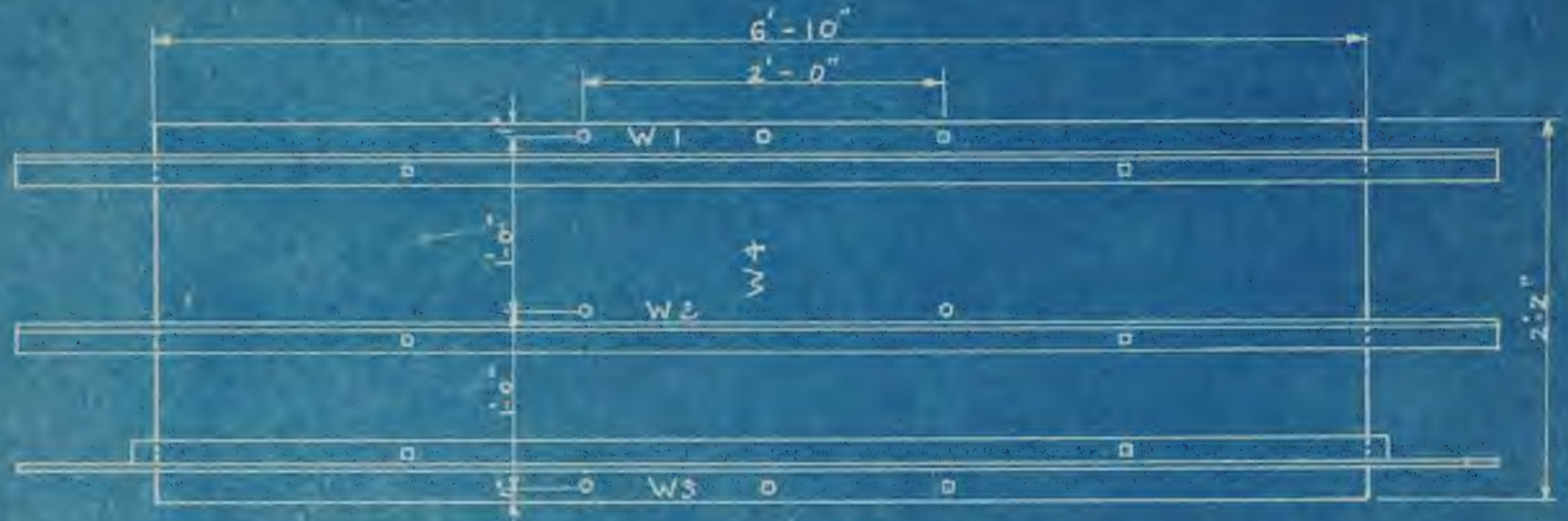


Specimen A
Plan

Strain Gauge Lines
Top and Bottom

o Concrete
+ Steel

Figure 1



Strain Gauge Lines Concrete

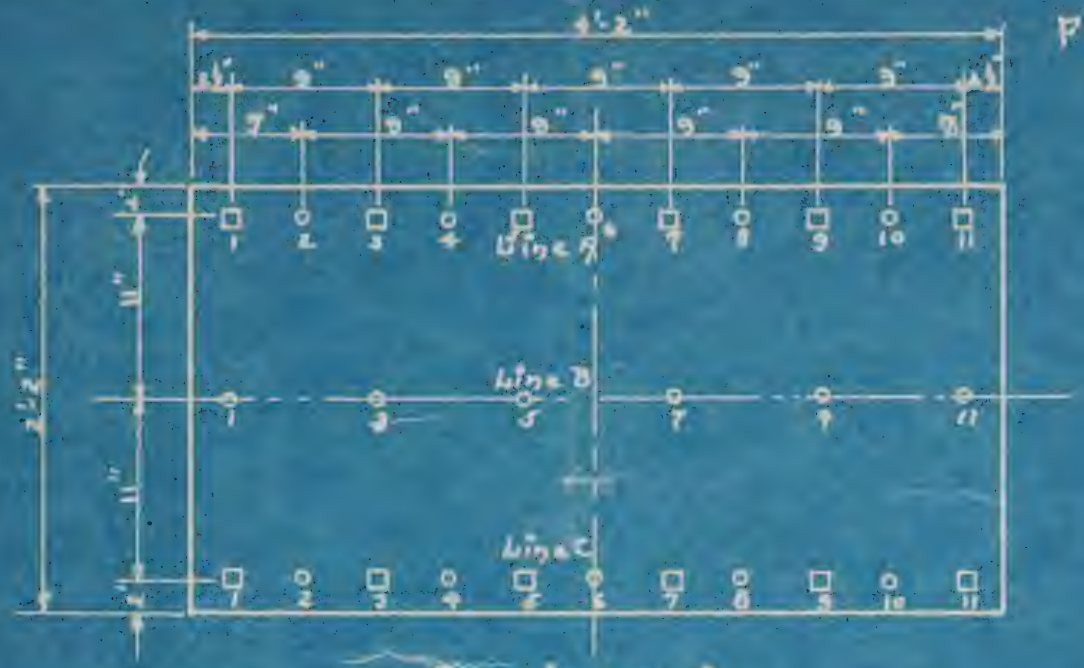
Sides

Elevation

Specimens A and B

Figure 2

Figure 3

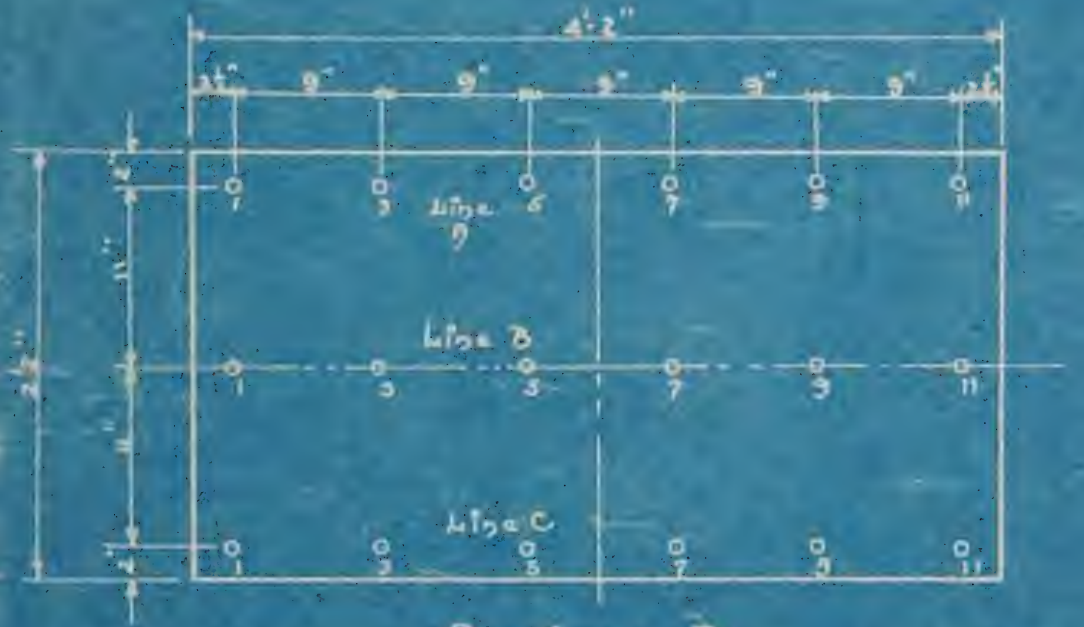


Specimen A

End View

□ Steel Bar

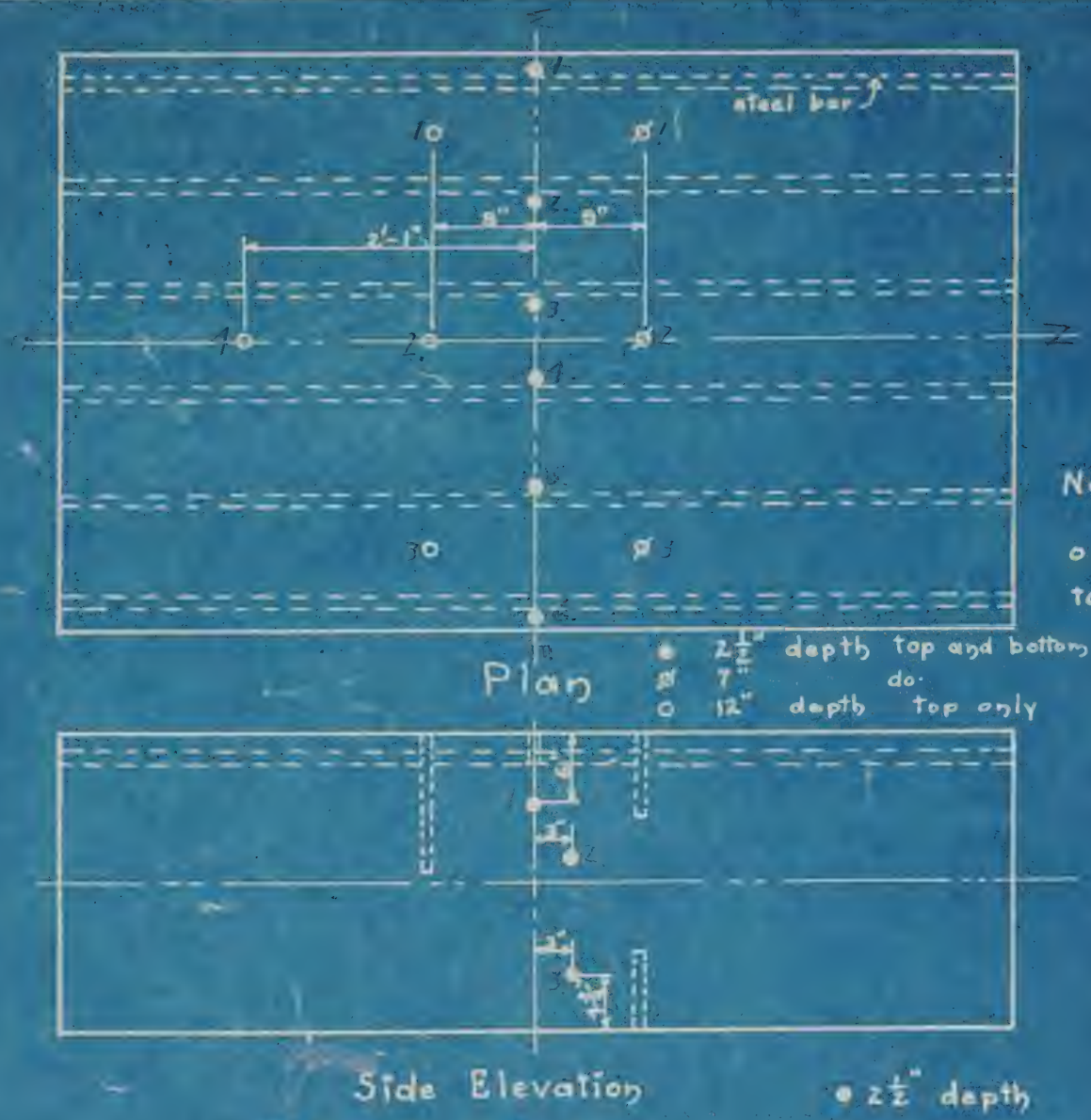
□ Plug in Concrete



Specimen B

End View

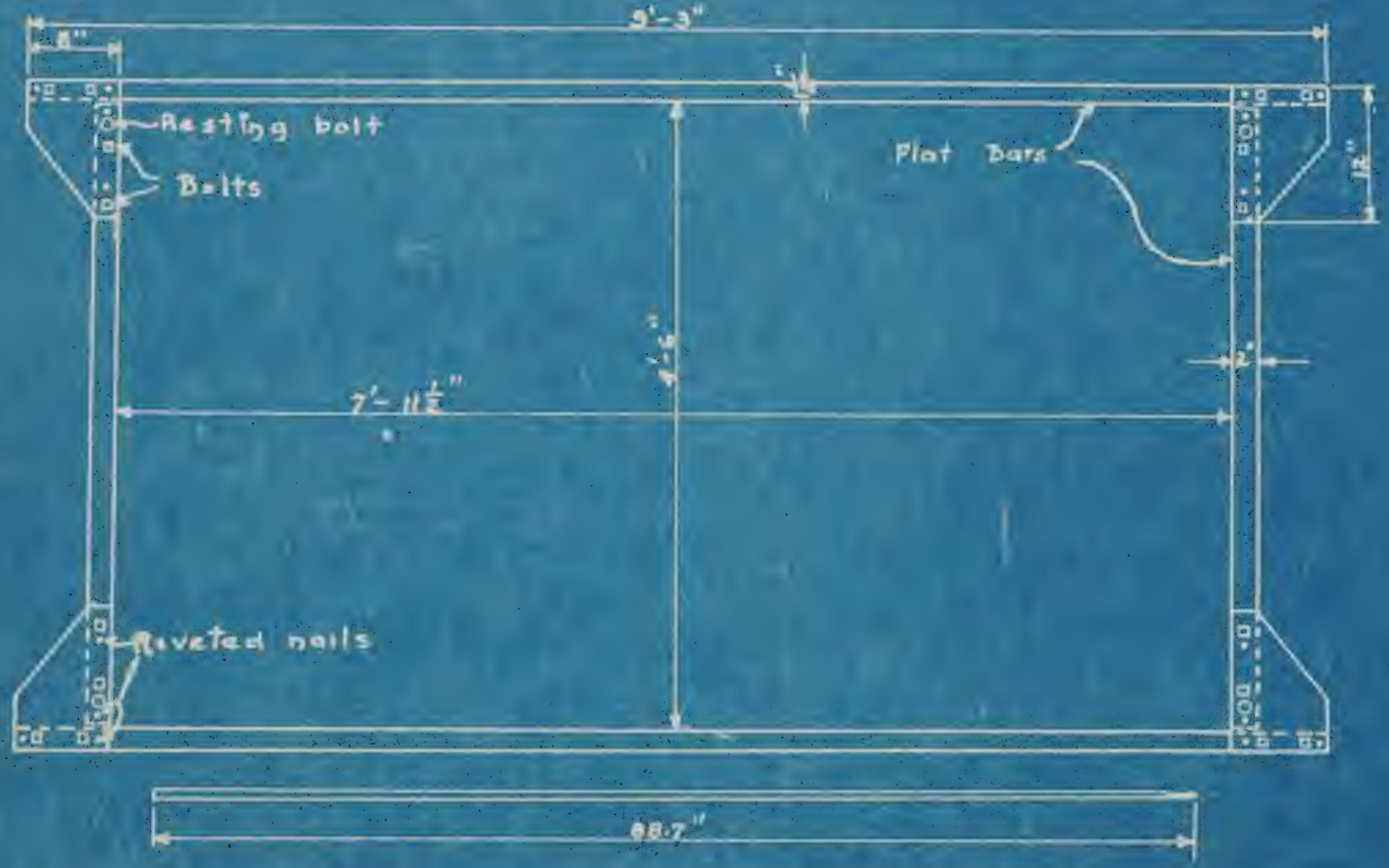
○ Plug in Concrete



Note:
Specimen B has only three 2½" wells top and bottom, center and edges.

Temperature Wells

Figure 4



Frame for taking Ames Dial Readings
and
Rod for checking Frame

Figure 5

5. Readings

Strain Gage Steel -- Twenty-four inch strain gage readings were taken at the center of Specimen A, gauge lines T_1, T_3, T_4, and T_6, see Fig. 1, on the top and B_1, B_3, B_4 and B_6 on the bottom. An 8 in. gauge line was on T_5 on the top. T_1 and T_3 were read from the west side, T_4, T_5, and T_6 from the east side. On the bottom B_6 was read first starting from the east side and going toward the west to B_1. This method was followed throughout the readings. A Standard bar was read before and after each set of readings. The dial of the strain gauge was always kept to left for readings on top and to the right for readings on the bottom.

Strain Gauge Concrete -- The concrete gauge lines in both specimen A and B are 24 in. long and identical. T_1 and T_2 (concrete) were read from the west side. T_3, T_4 and T_5 were read from the east side, the dial of strain gauge always being to the left. On the bottom B_5 was read first beginning from the east and going west with B_1 read last, the dial always being to the right. On the sides T_1 at the top was read first, the dial being to the right, and T_4 was read with the dial down. This procedure was followed throughout. The Standard bar was read before and after each set of readings. In working up the data, the standard bar was corrected to 60°F. for all strain gauge readings.

Ames Dial -- The Ames dial readings were always started from the west side at the south end. After reading the south row, the north row was read twice then the south row read again. This procedure was followed on all rows beginning at the top.

After all the rods on both specimens had been read, the frame was supported between the two specimens and the readings of the frame were taken with the two and Dial. The temperature of the rod was determined by a thermometer placed in contact with it.

Temperature -- Temperature readings were taken for the 2½ in. depths at five points on the top of Specimen A. These are alongside the top substantial bars. Three 7 in. readings, one near the edges and one at the center were taken, both at top and bottom. Four 18 in. readings were taken at the top. Five 2½ in. depths were taken on the bottom, which are also alongside the steel bars. Three 2½ in. readings were taken on the sides. All temperature wells are at the center of the block. For location of temperature wells see Fig. 4.

Specimen B had only three 2½ in. wells top and bottom, one near the edges and one at the center. The other temperature wells are the same as in Specimen A.

The thermometer was kept in the wells until no further movement occurred. Generally four thermometers were in use at one time. The temperature of the concrete was determined as soon after the strain gauge readings were taken as possible. These thermometers were calibrated so as to be accurate to within one-half of one degree Fahrenheit.

Seismic -- The blocks were weighed after all other readings had been taken. The wells for cores under the block and the block raised on jack placed on the corners of the molds.

To prevent the gauge points from rust, all points were coated with cup grease after each observation. The holes were reasonably cleaned out before taking the head reading. A copper scribe and waste were used for this purpose.

The frame, rod, strain gauges and standard bars were kept outside in cool in constant temperature at least twelve hours before taking any readings.

6. Availability Specimens

Test Cylinder — Three cylinders, 6in. by 12 in. were made during the pouring of both Specimen A and B. One cylinder was used for a concrete representative of the bottom, middle and top of the specimens, respectively.

Three cylinders were cured in damp sand up to the time of testing. One cylinder from each specimen was tested at approximately thirty, sixty and ninety days respectively.

7. Coefficient of Expansion Specimens

To determine the coefficient of expansion of the concrete in the large blocks, three cylindrical specimens approximately 30 in. long and 6 in. in diameter were made. The materials, except of water, was like of similar ones used in the concrete in the large blocks.

After curing for one week in a moist room, the specimens were taken out and strain gauge plugs placed in the specimens. Holes had been made in the specimens for this purpose and also for the temperature wells, by inserting short, round, steel plugs thru

holes in the sheet metal form. The temperature wells were filled up to the lower block. There were two molds for each cylinder, and four each plug.

Before any readings were taken one specimen was [illegible] because the observations were made only on the remaining two.

Method of Procedure -- Two series of readings were taken, one with the concrete moist and with varying temperatures, another with the concrete dry and with varying temperatures.

In the first series the specimens were well wrapped in cotton muslin, canvas cloth and wire burlap. This wrapping was kept damp at all times to keep the moisture content of the specimens as nearly constant as possible. Four readings were taken with the concrete moist at varying temperatures.

The specimens were then dried in a hot room for five days. A reading was taken then and the specimens wrapped up as before but without moving the wrapping. These observations were taken when the concrete was in this state. At every observation about readings were taken on each specimen. The temperature of the specimens was determined by thermocouples imbedded in the temperature wells.

Table 7 gives the data obtained.

TABLE 7

DETERMINATION OF COEFFICIENT OF EXPANSION

READING	SPECIMEN	WEIGHT lb.	WEIGHT oz.	TEMPERATURE Therm.#1	TEMPERATURE Therm.#2	STRAIN GAGE (Corrected)	EXPANSION	COEFF. OF EXPANSION	REMARKS
1	A	49	3¾	76.36°F.	72.0°F.	4287			27 hrs. in hot room
2	"	49	4¼	55.0	52.5	4207	.0061	.0000050	36 hrs. in laboratory
3	"	49	3	42.5	43.0	4095	.0111	.0000042	9 hrs. outdoors
4	"	49	3¾	76.7	72.5	4273	.0179	.0000050	32 hrs. in hot room
5	"	47	9¼	111.0	111.0	4479			Dried 2 da. in hot room
6	"	47	9¼	51.3	51.2	4128	.0355	.0000051	19 hrs. in laboratory
7	"	47	6¾	96.0	99.0	4325			23 hrs. in hot room
1	B	49	14¾	73.25	80.1	3076			
2	"	49	14¾	65.75	66.5	3000	.0076	.0000061	Same treatment as for Specimen A
3	"	49	12¾	42.5	43.5	2954	.0141	.0000053	
4	"	49	13¾	77.5	75.5	3043	.0184	.0000047	
5	"	49	1	112.25	110.5	3263			
6	"	42	1	52.1	49.0	2873	.365	.0000051	
7	"	49	0	89.5	86.5	3110	.0352	.0000053	
							av.	.0000052	

III EXPERIMENTAL DATA AND DISCUSSION

1. Evaluation of Figures.

Fig. 1 page 37, shows the location and arrangement of the strain gauge lines on the top of Specimen A. The numbering is started from the east side. Other details are shown quite clearly on the figure.

On the bottom of Specimen A, the arrangement of the gauge lines is similar to that on the top, except that there is no T_3 gauge line for steel.

Specimen B has no steel gauge lines. The concrete gauge lines are similar in arrangement to those on Specimen A.

Fig. 2 page 38, shows the location and arrangement of the concrete gauge lines on the sides of Specimens A and B. W denotes the east side, the east side gauge lines are E_1, E_2, etc.

Fig. 3 page 39, shows the arrangement of the Ames Dial points on the ends of Specimens A and B. The top line of points is marked Line A, the center line B, and the bottom Line C. Point number 1 is on the east side. The figures show the differences between the Specimens helped clearly without further discussion.

Fig. 4, page 40, shows the arrangement and location of of the temperature wells on Specimen A. The plan view shows the temperature wells on the top, and the side elevation the wells on the sides.

Specimen B has a similar arrangement and number of wells excepting the ½ in. wells top and bottom, of which there are only three on each surface. They are located one at each side and one in the center of the specimen.

Fig. 2, page 41, shows how division and general arrangement of the frame used in making the Steel Headings. The rod for securing to the frame is also shown. The figure shows how the frame was made right by fastening gusset plates to the flat bars by means of bolts and riveted nails.

4. Explanation of Photographs

The photograph opposite page 32 shows the specimens outside the north end of the structural laboratory. Specimen A is on the left and specimen B on the right.

The ends of the specimens have a coating of white paint, this was put on to prevent some moisture absorption at the ends. After several months of exposure the paint is peeling off to some extent.

Note in Specimen B the temperature wells on the side. The dark spots on the end of Specimen B are patches of grout, the end being broken somewhat from handling, necessitating the re-casting of two blocks. A similar patch is seen on the north end in the center.

The photograph shows more clearly how the blocks can be weighed by having scales placed under them and jacking the specimens off the blocks.

The photograph opposite page 33, shows Specimen A with the frame in place for taking the deep dial readings. The dial can be seen at the north end of the specimen. The construction of the frame is clearly shown in the view taken.

The wooden plugs on the top indicate the location of the steel strain gauge points.

The row of small openings along the center are the 3½ inch temperature wells, the 7 inch and 10 inch wells can also be seen.

The small white spots near the dark crosses indicate the plugs for the concrete strain gauge lines.

3. Evaluation of Tables

Table 4, page 30 gives the sieve analysis of the sand. The table is the average of three determinations. A Ro-Tap mechanical shaker was used for this purpose.

Table 5 gives the sieve analysis made of the gravel. The gravel became, and here shown. A little dust was found in the gravel but not enough to affect the concrete in any way.

Table 6, page 31 gives the results of the mortar briquette tests made on Standard Ottawa sand and the sand used.

The tests show a low strength at both ages tested. This low strength was due to making the briquettes on a cold day, the laboratory being cold for many days afterwards. The specimens were exposed to the cold air for one day after they were placed in water and kept there until tested.

None of the briquettes made of the sand used in the concrete for the blocks gave values below those of the standard Ottawa briquettes. Specifications generally require a higher tensile strength for the sand being tested than for Ottawa sand. In this case the sand tested had an average strength 8% greater at 7 days than the standard Ottawa and 8% greater at 40 days.

Table7 , page 46 gives the data obtained from the extrapolation of the coefficient of expansion for the mix of concrete used.

The strain gauge ratio used in working up the data was 4.09, which was verified by means of a screw micrometer.

From the table it is seen that the moisture content of the concrete does not affect the coefficient of expansion, that is, dry concrete and moist concrete have the same coefficient of expansion.

The agreement between specimens A and B shows that the value of the coefficient of expansion obtained is the correct one for the mix of concrete and the kind of aggregates used.

The last reading on Specimen A was not taken into consideration because of the large variation in temperature at the ends of the specimen.

4. Explanation of Curve Diagrams

From page 67-[illegible]16 curves for Specimen A are shown and from page 10-12 to 56-74 curves for Specimen B. The last cylinder curves are from page 191 to 196

Average curves were also made for all gauge lines of similar nature and position, these are found in page 67 to 83

The ordinates of the curve diagrams represent deformations in strain gauge divisions, one division being equal to the one-thousandth of an inch in the strain gauge diagram, and equal to one-thousandth of an inch in the dial diagram. In the curve diagrams for steel the stress in pounds per square inch is given on the right hand margin.

The abscissae of the curve represent the age of the specimen in days. Each circle represents the day a reading was taken, the months being also recorded on the diagram.

The full line marked total deformation shows the deformation actually gotten, the initial reading being taken as the origin and the subsequent readings referred to it as a base.

The dotted line marked temperature deformation gives the deformation due to temperature alone. The temperature of the concrete and steel bars was taken as that given by the readings taken on the temperature bells. The steel temperature was readily obtained since a temperature bell was alongside each bar. For the concrete a little interpolation was necessary as there, the concrete came into being between two temperature bells, both of different temperature. Generally the variation was only a few degrees. If the correct temperature of the concrete was not given, the error was slight since the variation in temperature from one reading to the next was comparatively great.

With the large number of temperature readings taken on the blocks or specimens, the temperature at any point in the specimen was known. The curves, as plotted, can therefore be taken as representative of the changes due to temperature.

The hot and dash line is the difference between the temperature and the total deformation curve. It, therefore represents the deformation due to shrinkage and moisture changes.

5. Phenomena of the Test

Concrete Gauge Lines on Top -- On pages 60 and 76 are shown the average curves for the strain gauge readings on top of Specimens A and B respectively. These show that when the specimens are exposed to the dry air of the laboratory, shrinkage of the concrete occurred continuing until taken outdoors. Specimen A showed a slight decrease even after taken outdoors.

When placed outdoors the concrete began to expand and reached its maximum after a wet rainy period. The temperature of the concrete during this maximum expansion was approximately 42° F lower than the initial reading for Specimen A and 33° lower than the initial for Specimen B. The shrinkage deformation curve for Specimen A did not go above the base line during this period, altho this curve does go above the base line slightly for Specimen B.

With rising temperature and only slight showers occasionally the concrete began to contract again reaching a second minimum during a period of dry weather and rising temperature.

Then followed several weeks of moist weather. Heavy rains preceded the final readings, but it should be noted that a drop in temperature also occurred. The concrete expanded rapidly during this period, the shrinkage deformation curve going above the base line.

Gauge Lines on the Side -- The concrete gauge lines on the sides follow the same general expansion and contraction as the ones on top. The variation is greater and more irregular, however, this can be accounted for by noting that the plugs on top and bottom of the sides are set in a rather large patch of neat cement mortar

which has an expansion coefficient greater than for concrete. The presence also of cracks in the cement mortar patches effects the expansion and contraction obtained.

Gauge Lines on the Bottom -- The shrinkage deformation curves for the bottom shown on pages 70 and 77, are above the base line except for one or two points. Specimen A showed a slight expansion the first few readings, however both specimens showed only slight contraction before being placed outdoors.

Specimen B expanded from the first reading outdoors, Specimen A showed contraction for the first reading outdoors, expansion followed with a maximum reading for both specimens on the same day as on top. A period of contraction followed which turned to expansion during the following moist weather.

While the curves for shrinkage and moisture deformation for the top and bottom of both specimens are similar in character it should be noted that the curves for the bottom are essentially above the base line indicating expansion at all times.

The first two readings on the bottom for Specimen A show expansion. Since the specimen was then indoors and drying out it would be expected that a contraction would occur. The steel diagram for this period does show a slight contraction. The apparent discrepancy is very slight, however, being only slightly more than one marked division on the strain gauge. This could be very easily caused by taking or getting an incorrect temperature or may be due to slightly different pressures on the strain gauge

while taking readings, this is very possible as the readings are taken with the strain gauge points up, the operator being in a more or less strained position.

The main difference between the top and bottom concrete strain gauge lines is in the amount of expansion shown. The following explanation is offered. A look at the photographs will show that the specimens are not far from the ground, about 3 feet. The bottom area will absorb moisture from the air equal to the top area, the bottom also collects moisture evaporating from the ground, the moisture absorbing area is within the real interior of the concrete. This collection of moisture was observed on several occasions, sufficient moisture being present to form 'beads of sweat'.

Even though the bottom surface is not subject to direct moisture through rainfall as the top surface, the bottom is not exposed to direct evaporation as the top is so that the moisture of the bottom is more at a fixed quantity during periods when the air is moist. This moisture expansion in the concrete since concrete expanded in moist conditions expands until the condition is removed.

Shrinkage — The effect of moisture has only been considered in the expansion percentage regardless contraction in the concrete, the effect of shrinkage will now be taken up. On pages 78 and 79 are shown the diagrams representing gain or loss in weight of Specimens A and B respectively.

On pg. 69 and 70 are shown the curves for the contraction of the concrete for the top and bottom respectively of Specimen A, note particularly the third to the last reading. The top shows a

decided departure from the initial while the curves is almost exactly the same as the initial reading. One note from the diagram on page 78 that the moisture content is considerably more than the initial amount.

A study of the diagrams on pp. 76,77 and 79 show the same condition for Specimen E. The increase in the moisture content is not as marked as in Specimen A, however, the same general tendency is apparent.

Although the size of the specimens and the number of readings taken is not sufficient to draw definite conclusions, a study of the curves would indicate that there is a shrinkage as the concrete taking place (that due to set), apart from the moisture saturation.

Steel Gauge Lines -- Diagrams on pages 67 and 68 show the curves for the steel gauge lines on Specimen A. The curve marked deformation due to concrete bears a striking similarity to the curves marked deformation due to moisture and shrinkage in the concrete gauge lines.

The curve showing the deformation of the steel due to the concrete, for the top, goes above the base line indicating tension. The concrete gauge lines do not show an expansion necessary to produce this tension in the steel. The bottom gauge lines agree better although the steel shows more compression toward the last part of the test than does the concrete.

Some part or all of this disagreement is probably due to the concrete gauge lines being on the surface while the centers of the steel bars are ½ inches from the surface. The concrete on the surface is therefore subject to more change than the concrete

several inches from the surface.

The Axes Dial Readings — The frame dial readings and the strain gauge readings do not agree as well as might be. The general trend is the same in both, i.e. when the strain gauge shows a rise the Axes dial readings do also.

Reference to pp. 73, 74 and 75 shows the avg. of moisture readings for Specimen A, and on pages 71 and 72 the steel readings. For Specimen B the readings are on pp. 80, 81 and 82.

Comparing the curves representing the moisture and shrinkage differentials of Specimens A and B, it is seen that the readings for A are above those for B, except for the center readings which agree rather well.

The Axes Dial readings for the steel bars follow very closely those of the concrete. This is to be expected since anything tending to cause error in the concrete affects the steel readings also, the readings being taken simultaneously.

Just why the Axes dial and the strain gauge readings do not agree better cannot be fully determined at the present time. With a larger number of readings and a longer period of time more definite conclusions can be drawn. Two contributing factors will be mentioned at this time. It was noticed in the case of Specimen A that the angle supporting the frame for the top row of readings had moved inward sufficiently to cause binding on the frame. How much error occurred at the readings could cause is unknown. Another possible cause of error is the frame. When the initial readings were taken the side bars of the frame were straight, later, stresses set up in the frame deformed it slightly. Any deformation of the frame would not cause any error from then on provided the deformation did not occur during a set of readings, since readings are taken

on the frame after each set of observations. There is a chance, however, that in moving the frame from one line to the next, the frame being somewhat flexible, that some change may occur.

6. Analysis of Shrinkage Stresses

Shrinkage in concrete can be determined by strain measurements but the stress due to shrinkage is not so easily determined. Deformation in plain concrete is not an indication of stress since the concrete flows gradually when subjected to stress because of its plastic nature.

If concrete is reinforced with steel and shrinkage takes place, the steel is put into compression. This is because steel does not flow under stress. The concrete is put into tension for the reason that the steel resists the shrinkage of the concrete.

To determine the stresses set up due to shrinkage, several experimenters have taken strain measurements on specimens of plain concrete and opposite specimens of reinforced concrete to find the relation between compressive stresses in steel and concrete due to shrinkage.

Probably the best and most recent investigation along this line was made by Tarath Sutsumi at the University of Illinois. His investigations were written although for small specimens. Two sizes of specimens were used, one being 4 by 8 by 24 in. and the other being 8 by 8 by 24 in. He found that stresses up to the allowable working stress of this steel may be set up due to the shrinkage of the concrete.

He derived formulas for calculating the compressive stress in the steel and tensile stress in the concrete from the unit deformation of plain concrete due to shrinkage. The derivation of these formulas can be found on pp. [illegible], Bulletin 180, University of Illinois.

The formulae are:

For the maximum unit compressive stress in the steel;

$$f_s = \frac{E_s d + E_c}{1 \quad np}$$

For the maximum unit tensile stress in the concrete;

$$f_c = p\, f_s$$

Where E_s = modulus of elasticity of the steel

$n = \frac{E_s}{E_c}$

p = ratio of steel area to the concrete area

e = shrinkage in a unit length of plain concrete

These equations are based on the following assumptions.

(1) The steel restrains the concrete uniformly throughout its cross section.

(2) The bond stress is proportional to the displacement of the concrete.

(3) There is no slipping of the bar, the bond stress being nil at the end and zero at the center. The maximum compressive stress will therefore occur at the center.

Assumption (1) cannot apply to any except specimens of small cross section, as used in I. Abrams's tests. For a specimen of large cross section, the action of the steel will be limited to a narrow body of concrete adjacent to the bar. The assumption that there is no slipping of the bar is not strictly true, hence the bond stress will not vary as the ordinates of a straight line. Any cracks in the concrete will also affect bond distribution, bond action will be concentrated in the sound sections, with no bond action at the cracks.

(e) Comparison of Surface and Core Observations (Total Deformation)

The total deformation at the top of Specimen A as determined by the Amsler dial is given on page 184 The outer points are the outer steel bars on which the strain gauge readings were taken. The base line for each day of observation gives the deformation from the initial reading. A tendency toward a greater shrinkage at the edges can be seen.

On page 187 the total deformation for the top row of Specimen B is given. The curves do not show enough uniformity to draw any conclusions.

On pages 185 and 188 the total deformation for the center row of plugs of Specimens A and B are plotted. The deformations are rather uniform across the width of the Specimens, the last two readings show a variation in Specimen B.

On page 186 the deformations for the bottom row of Specimen A are plotted. Specimen B had two plugs located during the removal between so that they would not be compared to the other readings. The curves for the center of Spec. A are uniformly higher on the east side than on the west side. The reason for this is not known, although it might have been caused by an error in the initial readings. A gradual slipping of the frame while the initial readings were being taken could account for this tendency. This seems to be reasonable since all the curves vary in the same way. If the curves were adjusted so as to be horizontal, the deflection of the outer bars would be greater than that of the inner bars.

The Ames dial readings were averaged for each row of both specimens and plotted on pages 182-183 to see if there was any variation in a vertical plane. Both specimens show that the top and bottom shrunk more than the center. The slopes of the curves vary, which is an indication that there is no initial error entering in.

The average deformation of the middle row D of the Ames dial points, together with the average of the 4a in. strain gauge readings at the top, bottom and sides of both specimens were plotted. These are shown on pages 180 and 181
These curves were plotted to see what relation there was in the unit deformation in the concrete around the central portion of the specimens as determined by the strain gauge readings on the sides, the 4a in. one with, and the Ames dial readings taken on the center row of plugs at the ends.

The curves for Specimen A show that the strain gauge readings agree nicely with each other, the Ames dial curve however is considerably above the others, varying more than several hundred percent from the average reading.

In curves for Specimen B, the Ames dial curve agrees fairly well with the two strain gauge curves. The gauge line near the bottom is somewhat above the average varying around 20 percent from it.

The diagrams on pages 176-179 show the total deformation of the concrete in the 24 foot batter of Specimens A and B as determined by the 4a in. strain gauge. These diagrams do not indicate any systematic variation, the variations that occur being

small and erratic. It should be noted, however, that the outside gauge lines are 7 in. from the edge of the block. The diagram implies that the deformation is uniform between points 7 in. from the edge of the block, there is no data indicating that this interaction is more uniform up to the edge, than at the center.

The above discussion has brought out the following tendencies of the present test.

The shrinkage at the top and at the bottom of a concrete block, like the ones used in these tests, is greater at the extreme edges than at the center.

The deformation in the central portion of the block is uniform, both in the top and bottom.

The deformation, across the middle of the block is markedly uniform from edge to edge.

The average curves for the top, center and bottom rows of dial plugs show a greater shrinkage for the top and bottom rows. than for the middle row.

The usual assumption that the entire cross section has the same shrinkage is not borne out by this test. In other words a plane section before shrinkage does not remain plane after shrinkage.

(2) The Thermal Coefficient of Concrete

The use of the correct thermal coefficient is very important in working up the data such as obtained in this test. The method of deriving the proper coefficient for the concrete used in this test was discussed on pages 44 and 45.

It was found that this concrete had the same thermal coefficient when in a wet state as in a dry state. The average

value obtained was 0.000008

This value is slightly below the accepted value of 0.000008, which several experiments have obtained. In some recent experiments, Professor T. E. Stern obtained values from 0.000040 to 0.000060, depending on the temperature of the concrete. He found that the thermal coefficient varied with the temperature.

In determining the deformation due to temperature in this test, the value of 0.000008 was used as determined for this concrete. Using this coefficient the deformation due to temperature accounts for a large part of the total deformation and may account for all of it during some periods of time.

In determining stresses due to shrinkage or other causes, the proper coefficient of thermal expansion must be known to correct for the temperature changes. Since the resulting deformation after the temperature correction has been made is usually small, compared to the total deformation, a wrong thermal coefficient may cause considerable error in the results.

On pages 18 and 19 are shown the diagrams for the average temperatures of the top, bottom, sides and middle of the slab for Specimens A and B. These diagrams show the similarity between the total deformation curve and the temperature curve. From these diagrams it will be seen that there is very little difference between the temperature of the concrete surface and the concrete in the core, the variation generally being only a few degrees.

(c) Shrinkage Stresses in the Steel

The diagrams showing the average curves for the strain gauge readings on the steel, for the series of Specimen I are shown on pages 67 and 68. In the early stages compression in the steel due to shrinkage of the concrete is seen when the block was lowered, on removal outboard, this compression changed to tension, the concrete having expanded.

The stress in the steel due to the deformation of the concrete can be taken from these diagrams as for the right hand margin. These measured stresses are compared with a few stresses calculated by Hasselmeyer's formula. The calculated stress as given by the formula is the maximum, hence for a gauge length of 24 in. in an 96 in. length of concrete, the average stress will be 96 percent of the maximum. See paper 20-21, Bulletin 149. In calculating these stresses, the unit shrinkage of plain concrete as measured on Specimen B has been taken.

TOP

	Jan.14	Jan.21	Jan.28	Feb. 4	Apr. 4
Measured Stress	-1700	-1850	- 575	000	-835
Calculated "	- 490	-1538	-1440	-558	-735

BOTTOM

Measured Stress	- 80	-000	-1080	1480	-840
Calculated "	-558	-140	480	1140	840

It is evident from a study of the above tables that for large distances that is taken used in this test, the formula for calculating stresses in the steel bars will determine the measured

on the surface of plain concrete does not apply. This variation can be seen even in the small specimens as used by Matsumoto. See Bulletin 126, University of Illinois.

(d) The Effect of Moisture Content Upon the Shrinkage of Concrete

Diagrams showing the gain or loss in moisture of Specimens A. and B are shown on pages 78 and 79.

The first part of the curves show a drying out of the specimens. This part of the curve corresponds to a similar one in the diagrams of the Ames dial readings and strain gauge readings. When there is a long continued period of rainfall, the moisture and the shrinkage deformation curves show an increase in the moisture content and a corresponding expansion of the concrete. On the day when the specimens contained the maximum amount of water, the readings did not show a corresponding increase in expansion. This reading did not show a corresponding increase in expansion. This reading followed a single day of heavy rainfall. The rain, being of short duration, penetrated only the outer surface of the specimen not affecting the interior. This is shown by the diagram for the average curves for the middle row of Ames dial points, Specimen B, page 81.

With small specimens, moisture will quickly penetrate through the entire cross section, giving large expansion deformations. Table 4, shows the expansion coefficients obtained by numerous experimenters on different mortars and concretes. On specimens of such size as were used in this test, shall penetration of moisture does not affect the main body of the concrete.

7. SUMMARY

Although no final conclusions can be drawn from the present investigation due to its limited nature, a brief summary of the main points brought out will be given.

1. A plain specimen before shrinkage does not remain plane after shrinkage.

2. The average unit deformations of the central areas of the top, sides, and bottom generally agree fairly well.

3. In the plain specimen the unit deformation of the middle row of face dial points (core of block), agreed remarkably well with the unit deformations as determined from the other surfaces, in the reinforced specimen this agreement was not so good.

4. The thermal coefficient of wet and dry concrete is the same, being 0.000052 for concrete as used in this test.

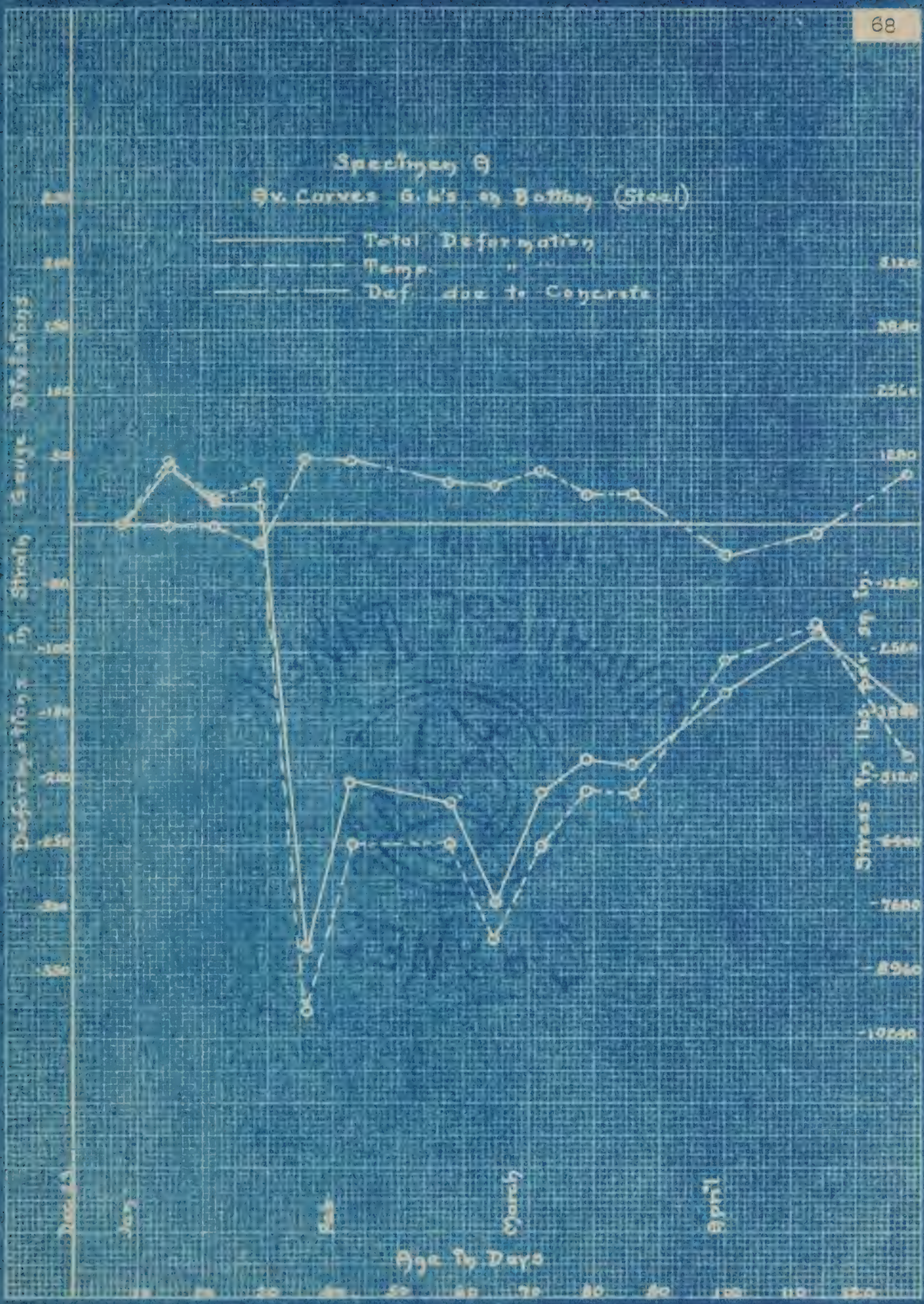
5. Temperature deformations account for a large part of the total deformations and may account for all of it during some periods.

6. Unless long continued, the effect of moisture is not apparent in the main body of large specimens as used in this test.

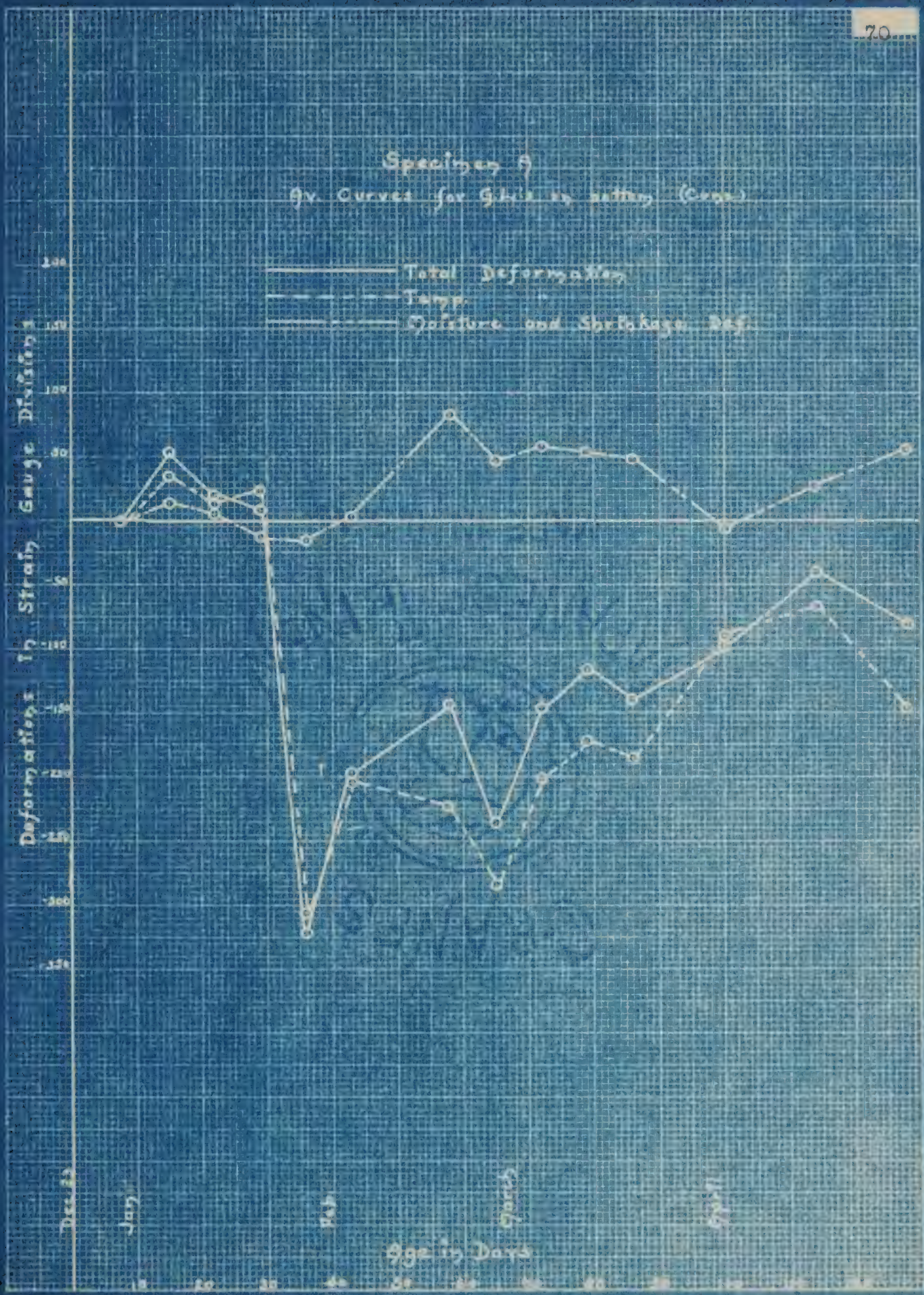
7. Shrinkage stresses in the steel as determined from deformations on plain bars do not agree with measured stresses.

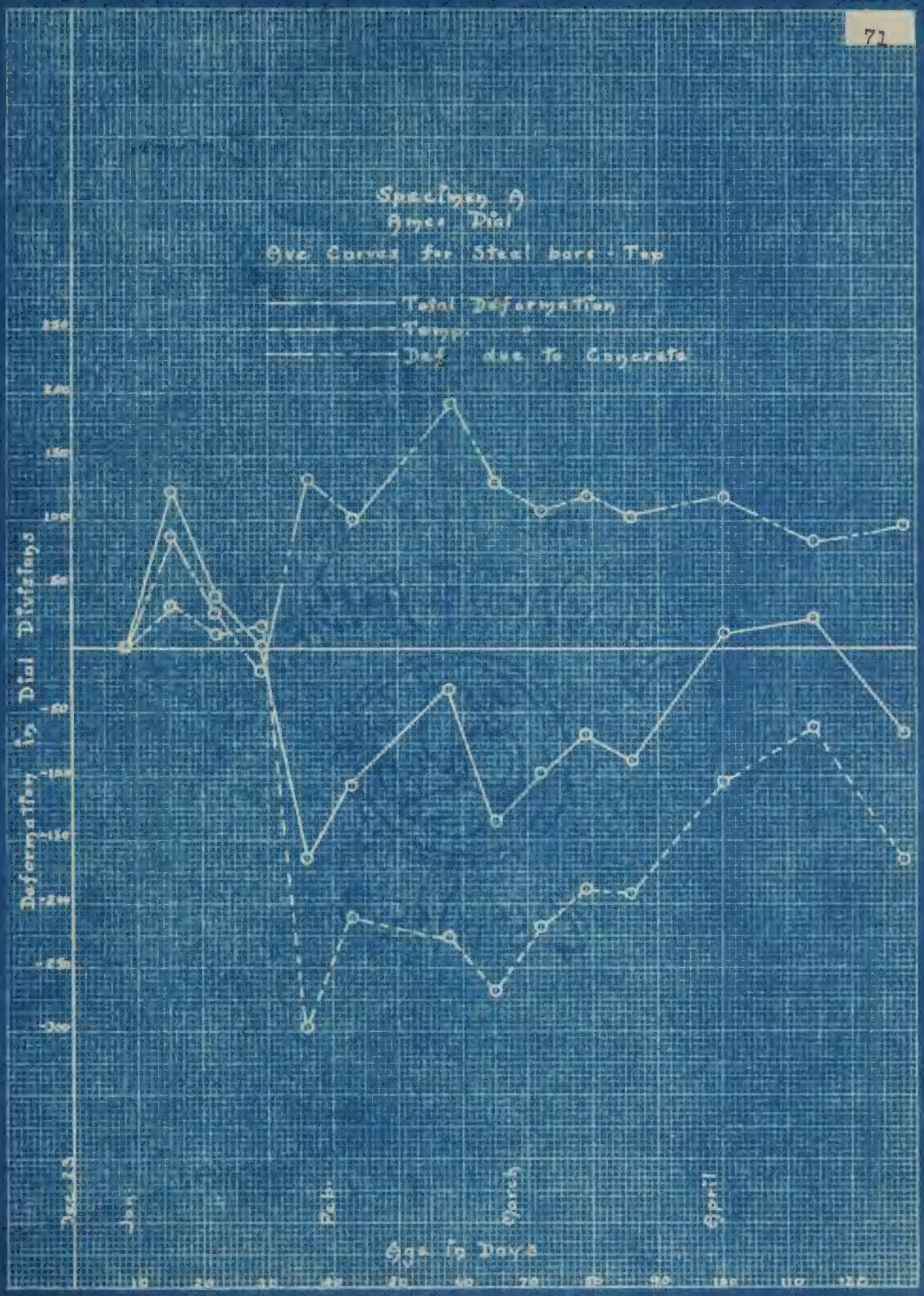
8. The present investigation points out the need of further investigation and study of the deformations in concrete produced by temperature and moisture changes.

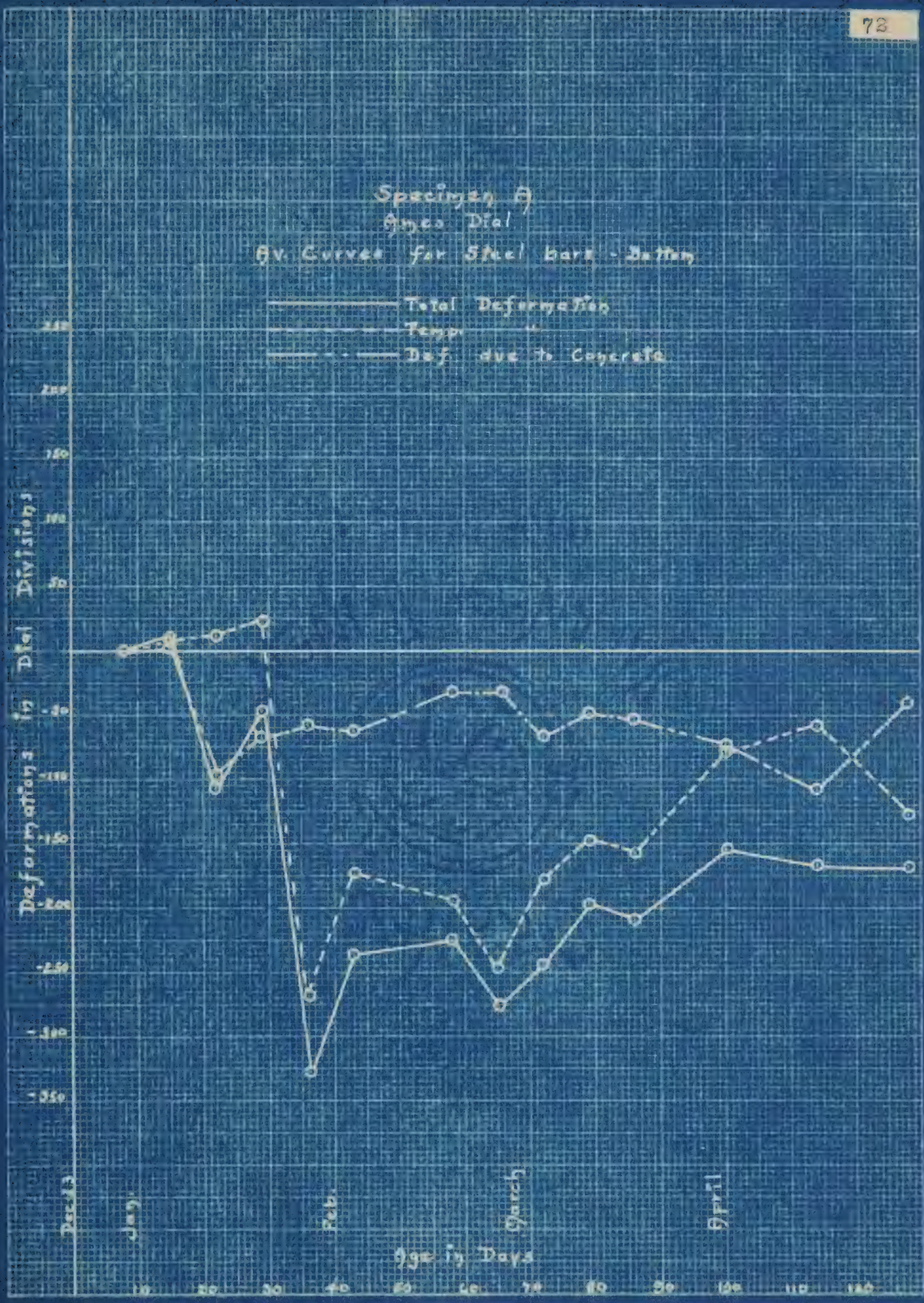
Specimen B
Curves for 6-18 on Top (Steel)
Total Deformation
Temp.
Def. due to Temp.
Deformations by Strain Gauge Divisions
Stress in lbs. per sq. in.
Age in Days
Jan.
Feb.
March
April

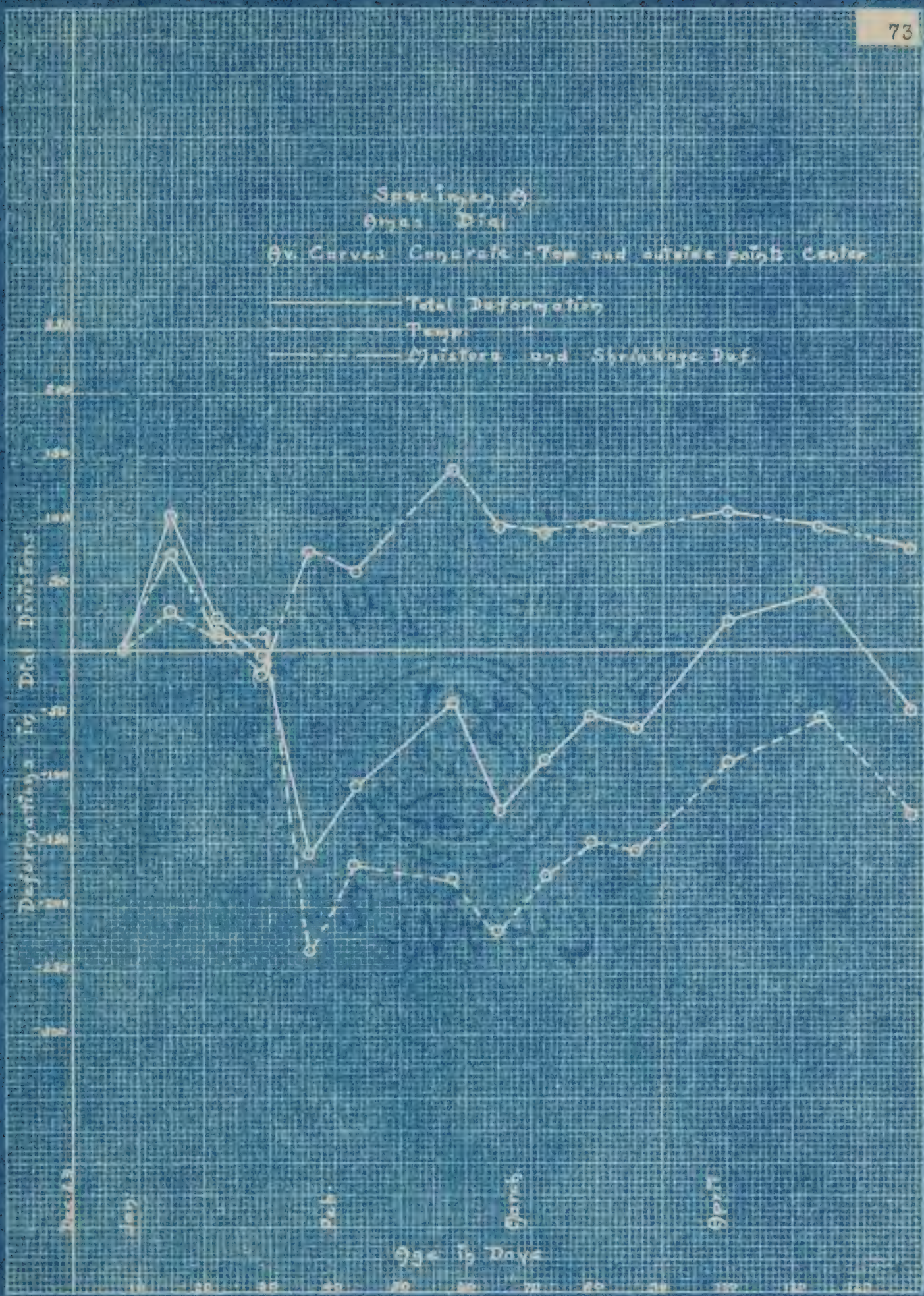

Specimen G
Gv. Curves G.W's on Bottom (Steel)
Total Deformation
Temp. "
Def. due to Concrete
Deformation in Strain Gauge Divisions
Stress in lbs. per sq. in.
Age in Days
March
April

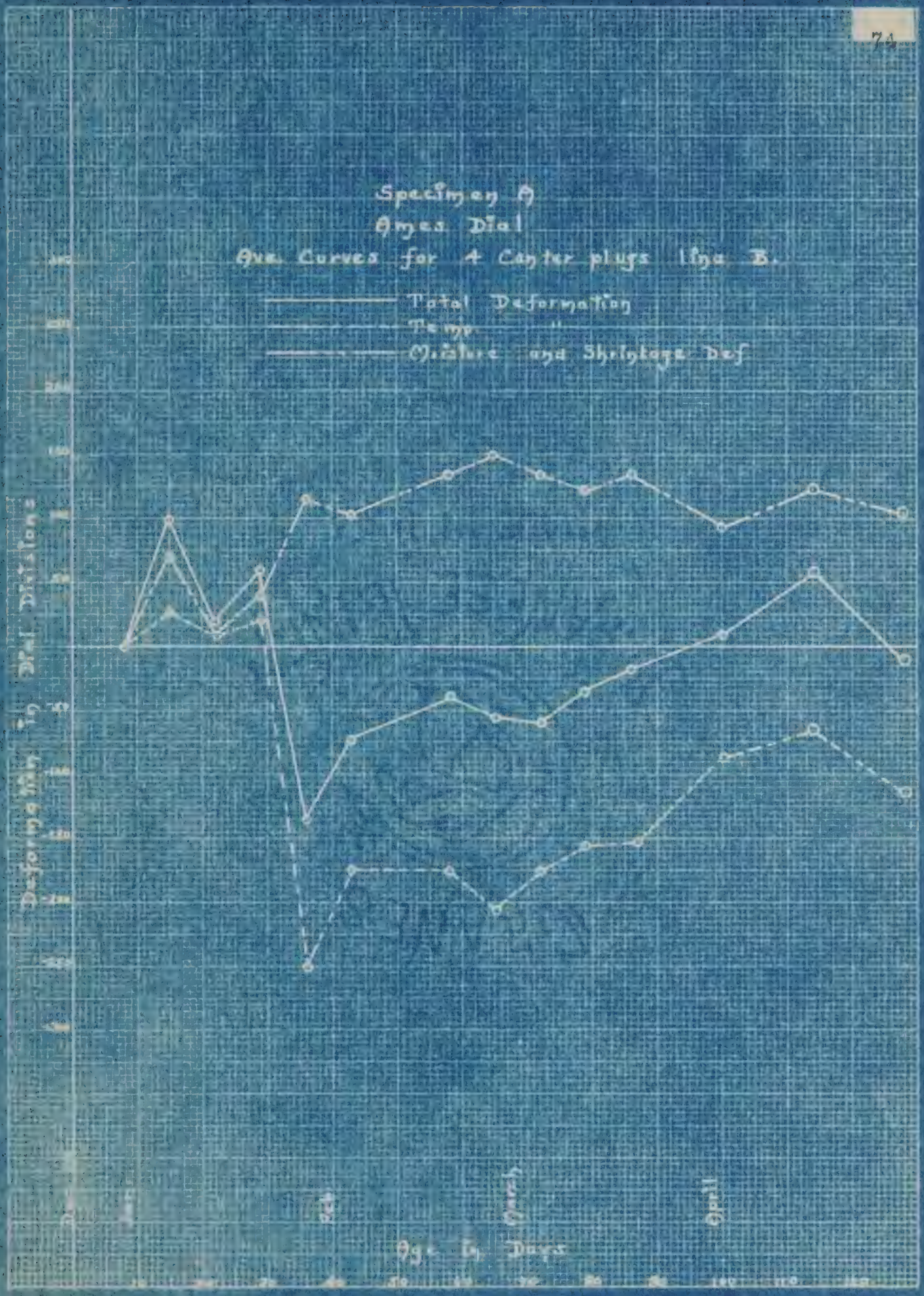
Deformation in Stalk Gauge Divisions
Jan.
Feb.
March
April
Egg Ty Days

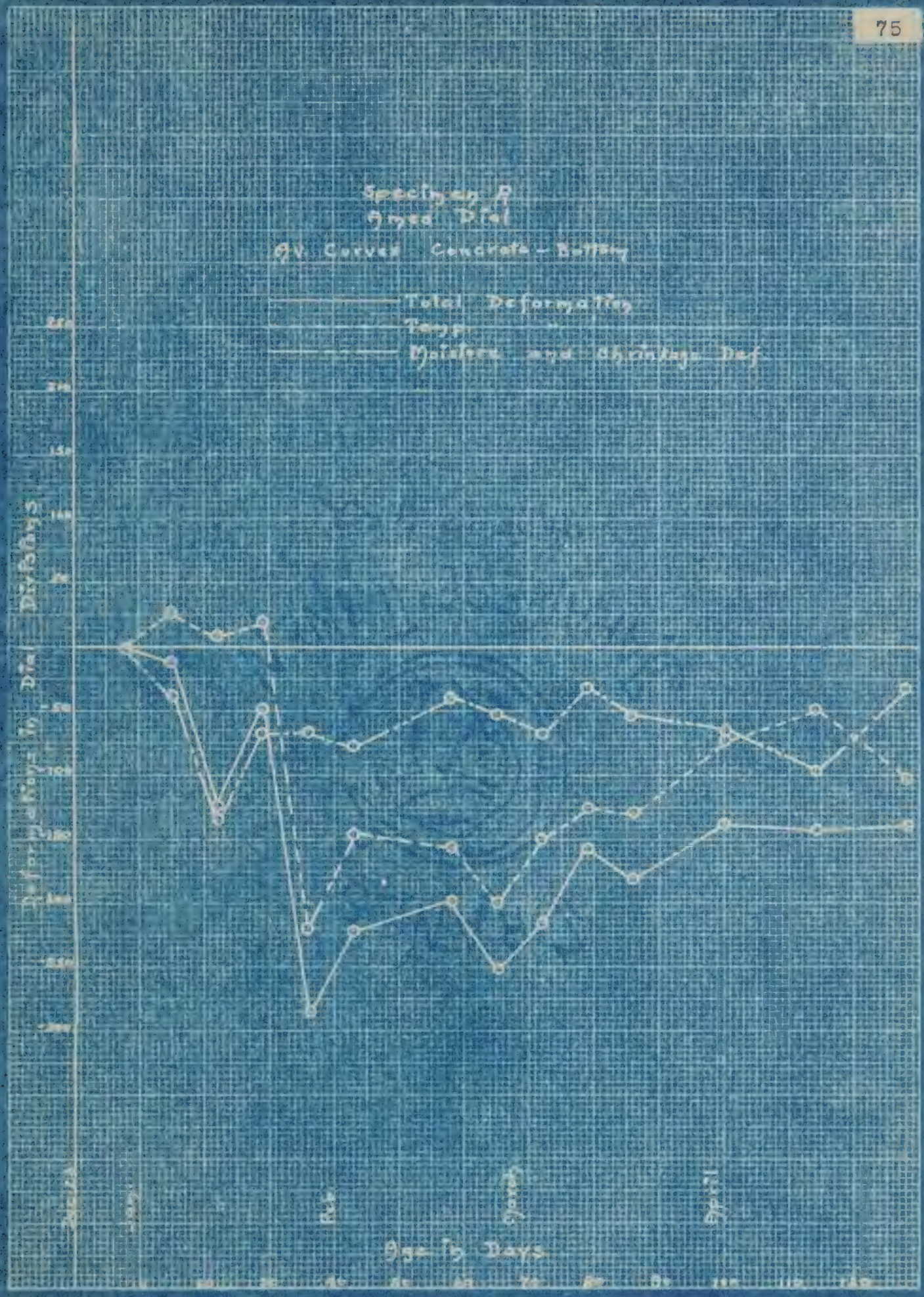

Specimen 9
Av. Curves for Skin in bathing (Cross)
Total Deformation
Temp.
Deflection and Shrinkage Def.
Deformations in Strain Gauge Divisions
Age in Days
Dec 31
Jan
Feb
March
April


Specimen A
Ames Dial
Avg. Curves for Steel bars - Top
Total Deformation
Temp.
Def. due to Concrete
Dial Divisions
Deformation in
Jan.
Feb.
March
April
Age in Days


Specimen A
Ayer's Dial
Av. Curves for Steel bars - Bottom
Total Deformation
Temp. "
Def. due to Concrete
Deformations in Dial Divisions
Age in Days
Dec 15
Jan.
Feb.
March
April

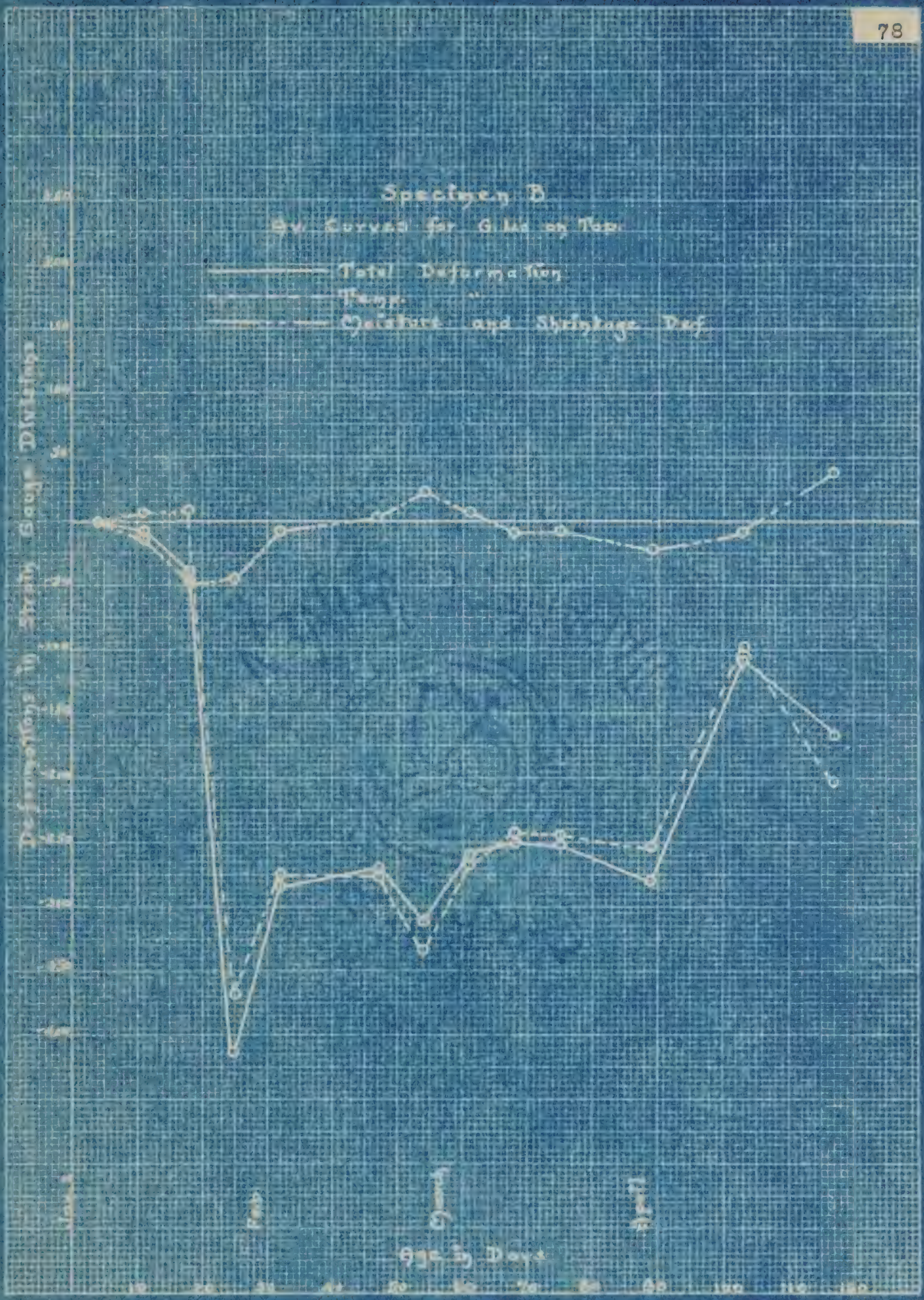

Specimen 3
Gauge Dial
Gr. Curves Concrete - Top and outside point Center
Total Deformation
Temp.
Elastic and Shrinkage Def.
Deformation in Dial Divisions
Age in Days
Jan.
Feb.
March
April

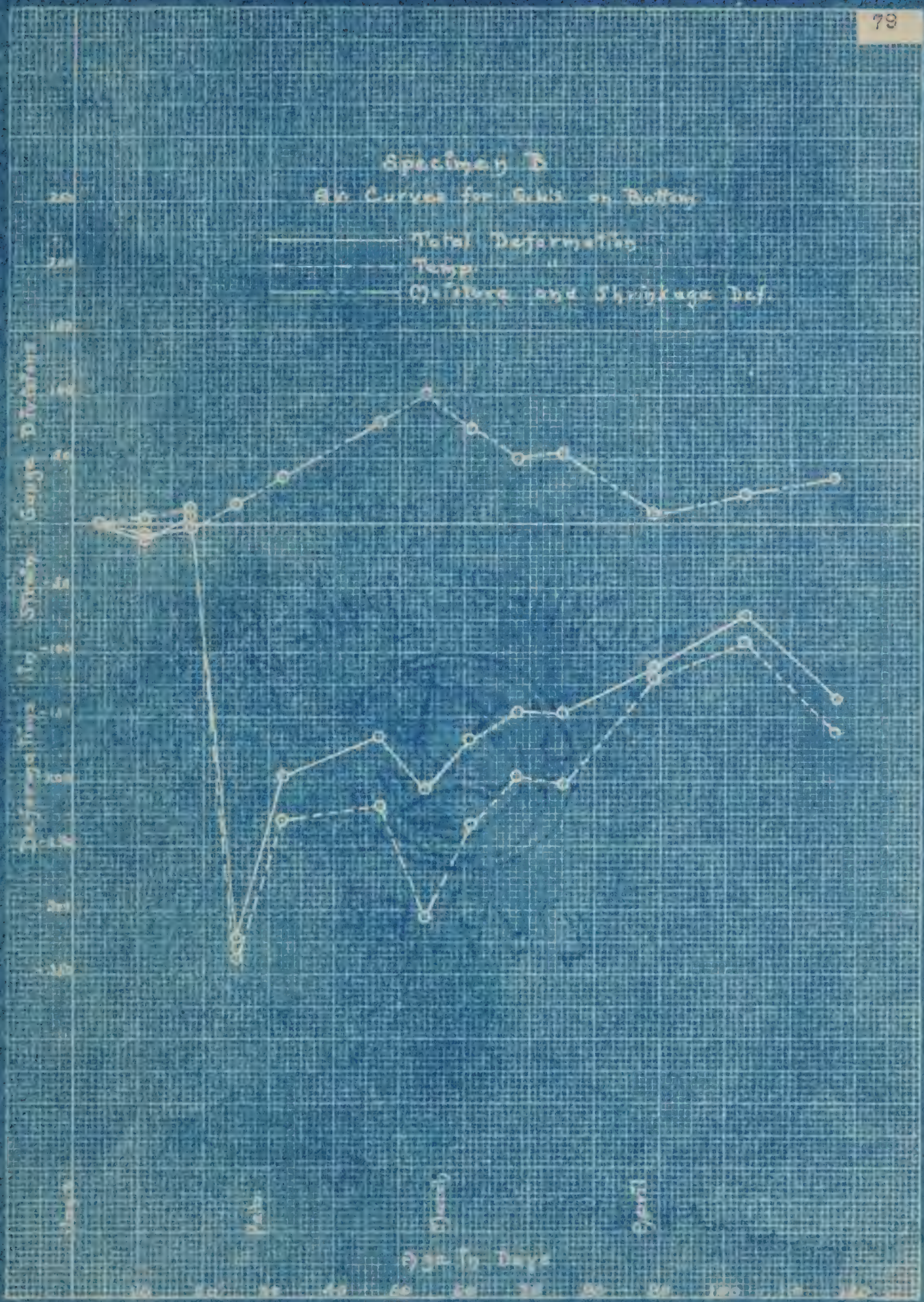

Specimen A
Ames Dial
Ave. Curves for 4 Center plugs line B.
Total Deformation
Temp "
Moisture and Shrinkage Def
Deformation Mil. in Dial Divisions
Age in Days
3rd
March
April

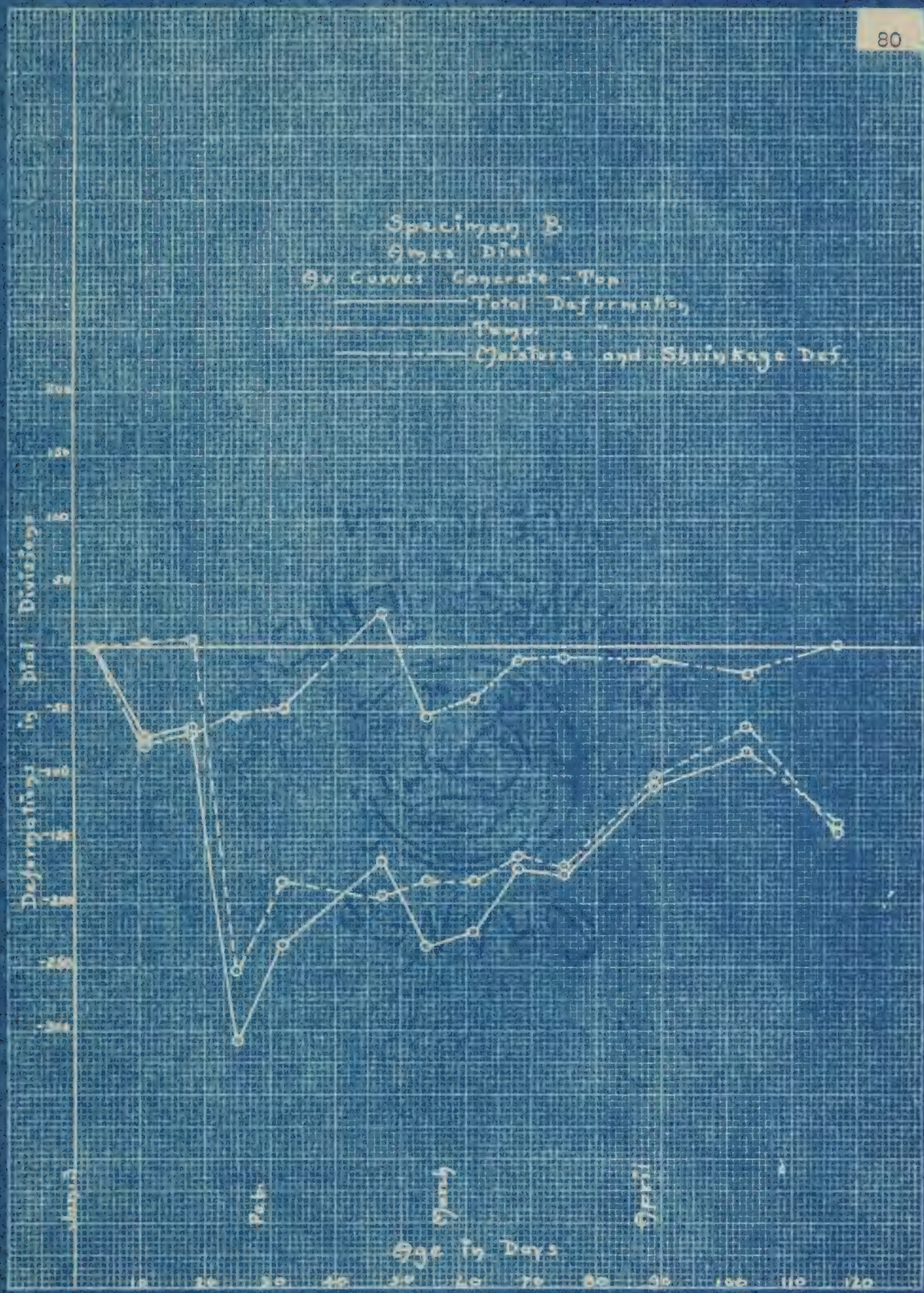

Specimen A
Gyred Dial
Gy. Curves Concrete - Batting
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days

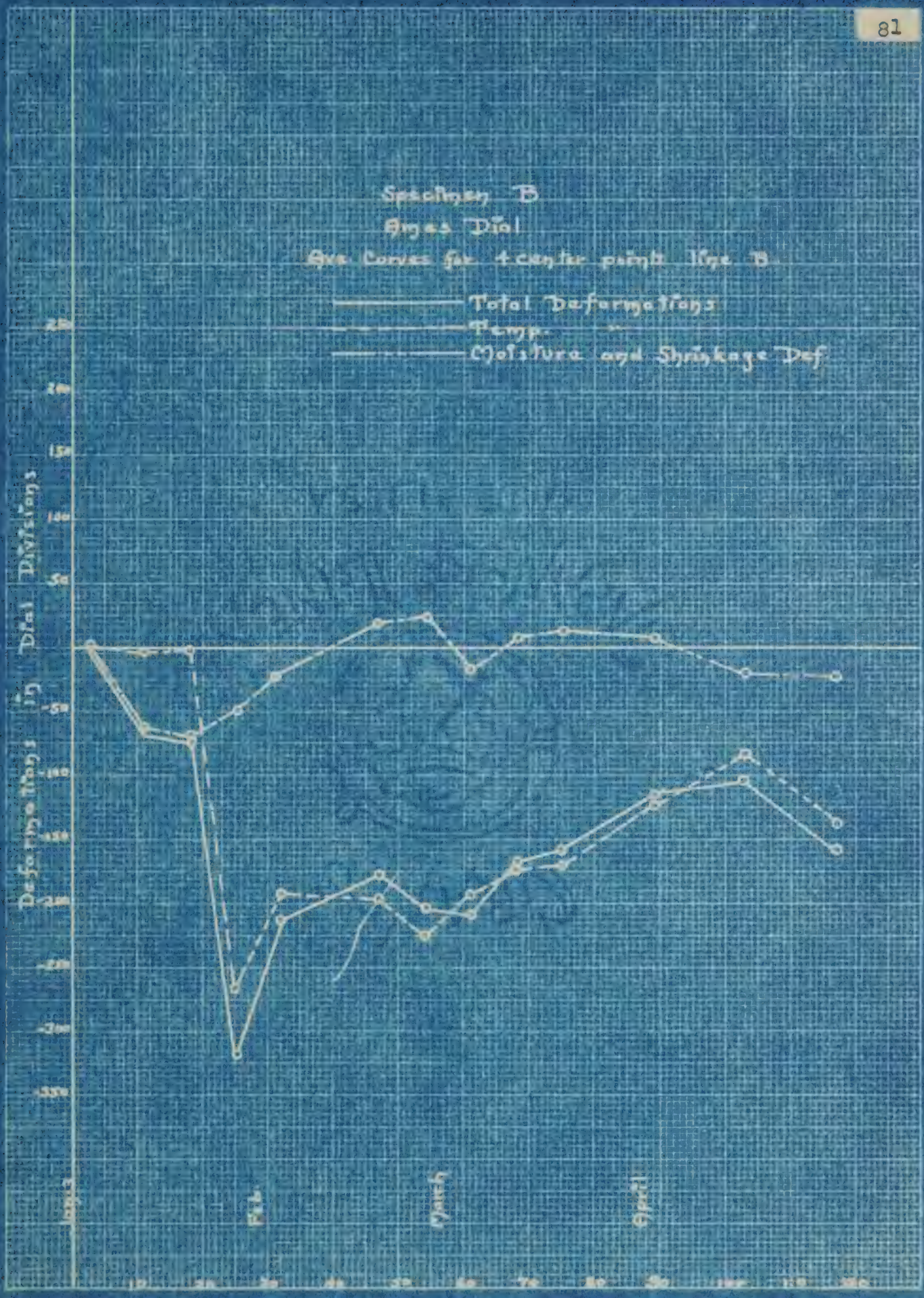
Specimen 9
Daily and Mean in Solution
Percent of Compressive Strength Gained at Test
Taken Out Dry
Age in Days
Jan
Feb
March
April

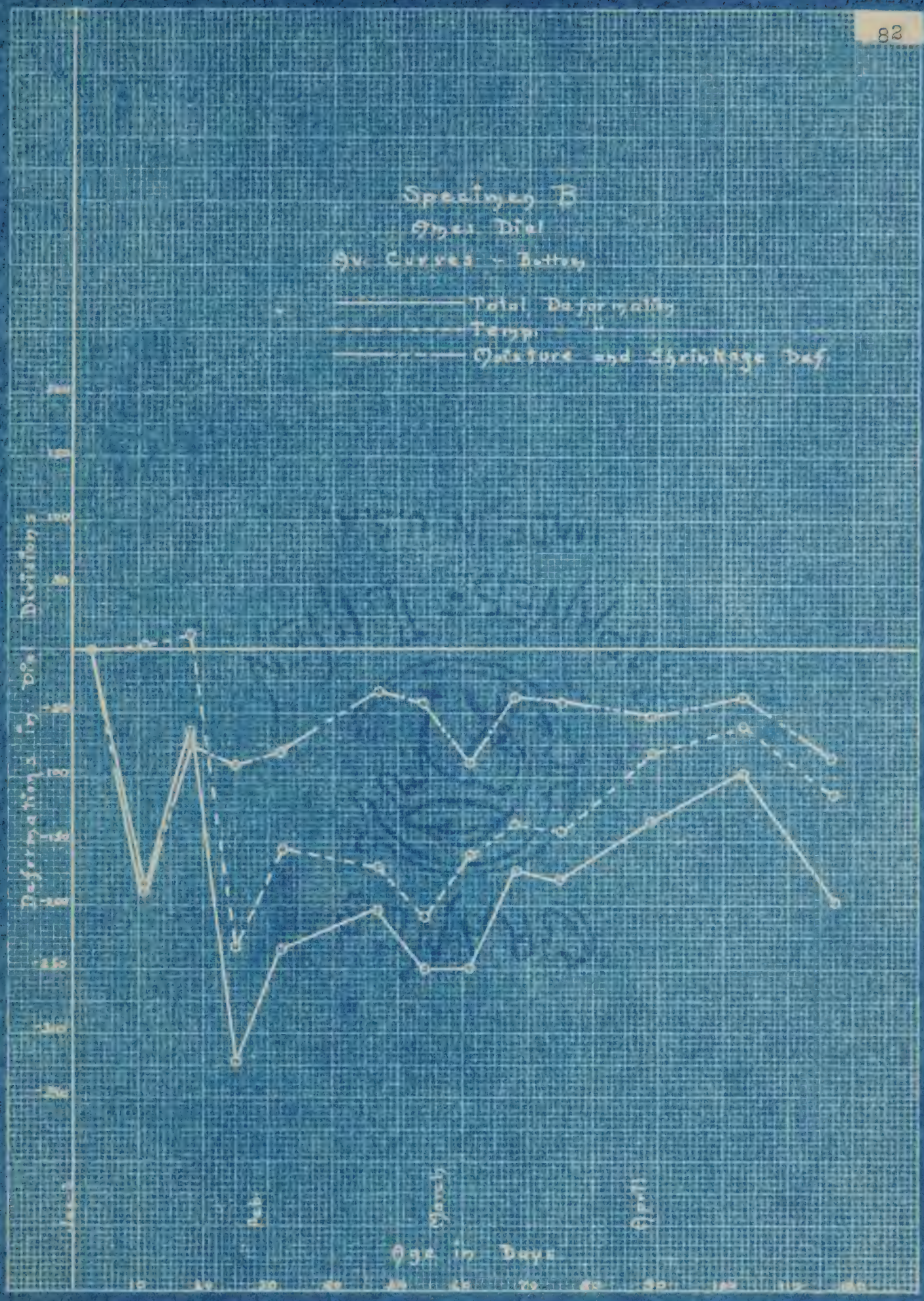
Specimen B
Gain and Loss in Moisture
Pounds of Moisture Gained or Lost
Age in Days
Taken Outdoors
Feb.
March
April
Jan. 1
10
20
30
40
50
60
70
80
90
100
110
120


Specimen D
Total Deformation
Temp.
Creepture and Shrinkage Def.
Age in Days

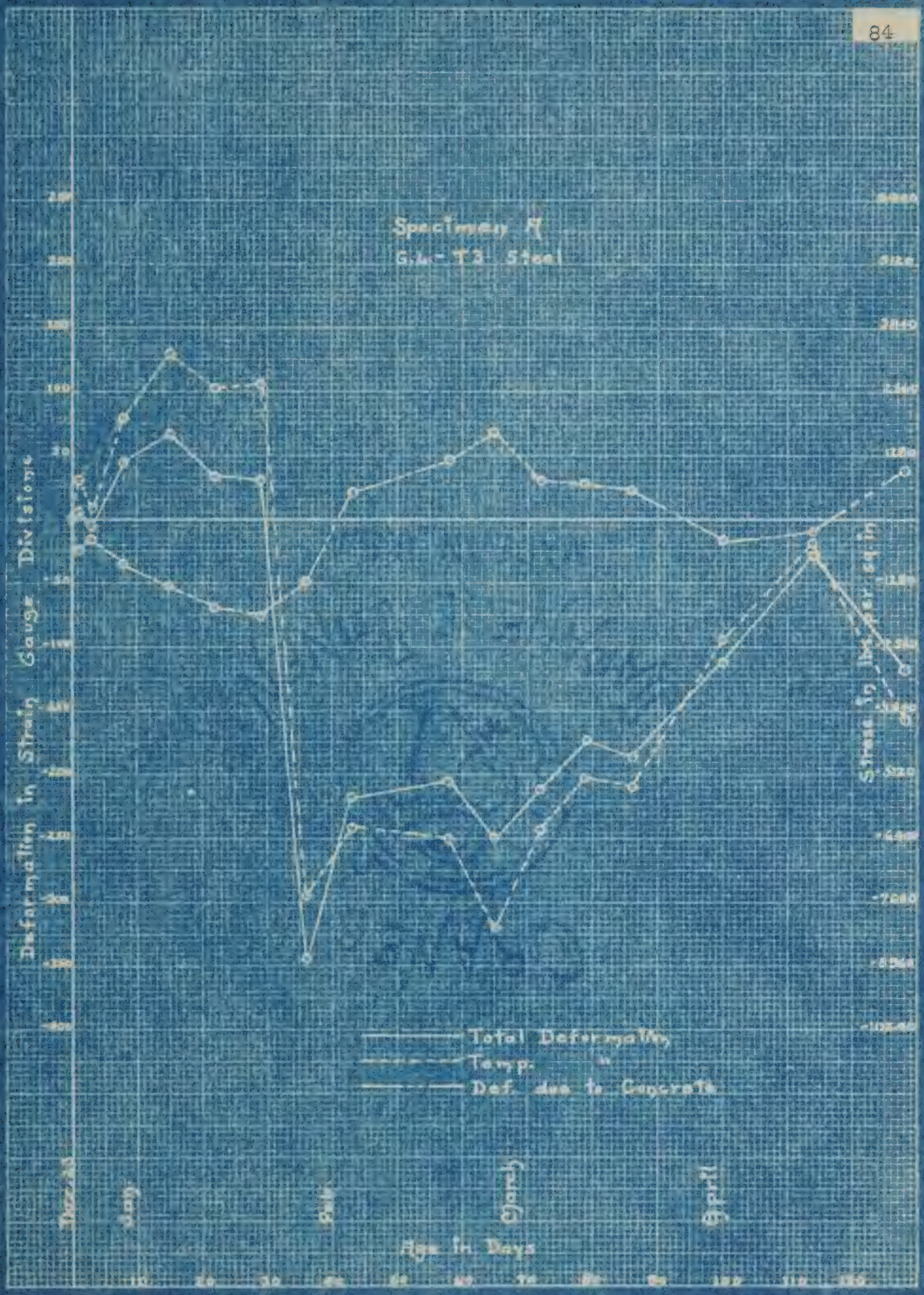

Specimen D
Gis Curves for Gauge on Bottom
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformation in Strain Gauge Division
Age in Days

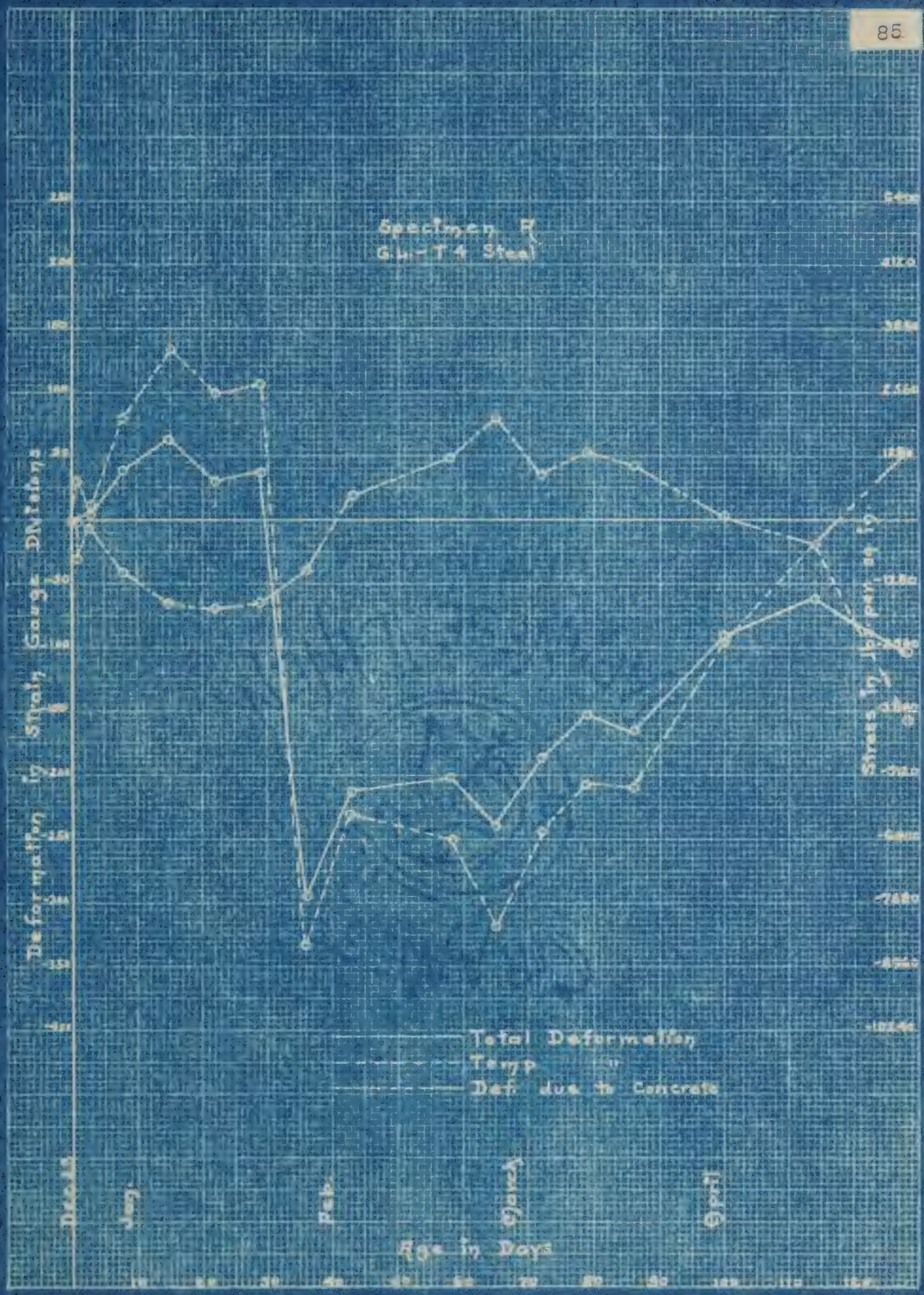

Specimen B
Gage Dial
Gr. Curves Concrete - Top
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformation in Dial Divisions
Age in Days
Jan.
Feb.
March
April

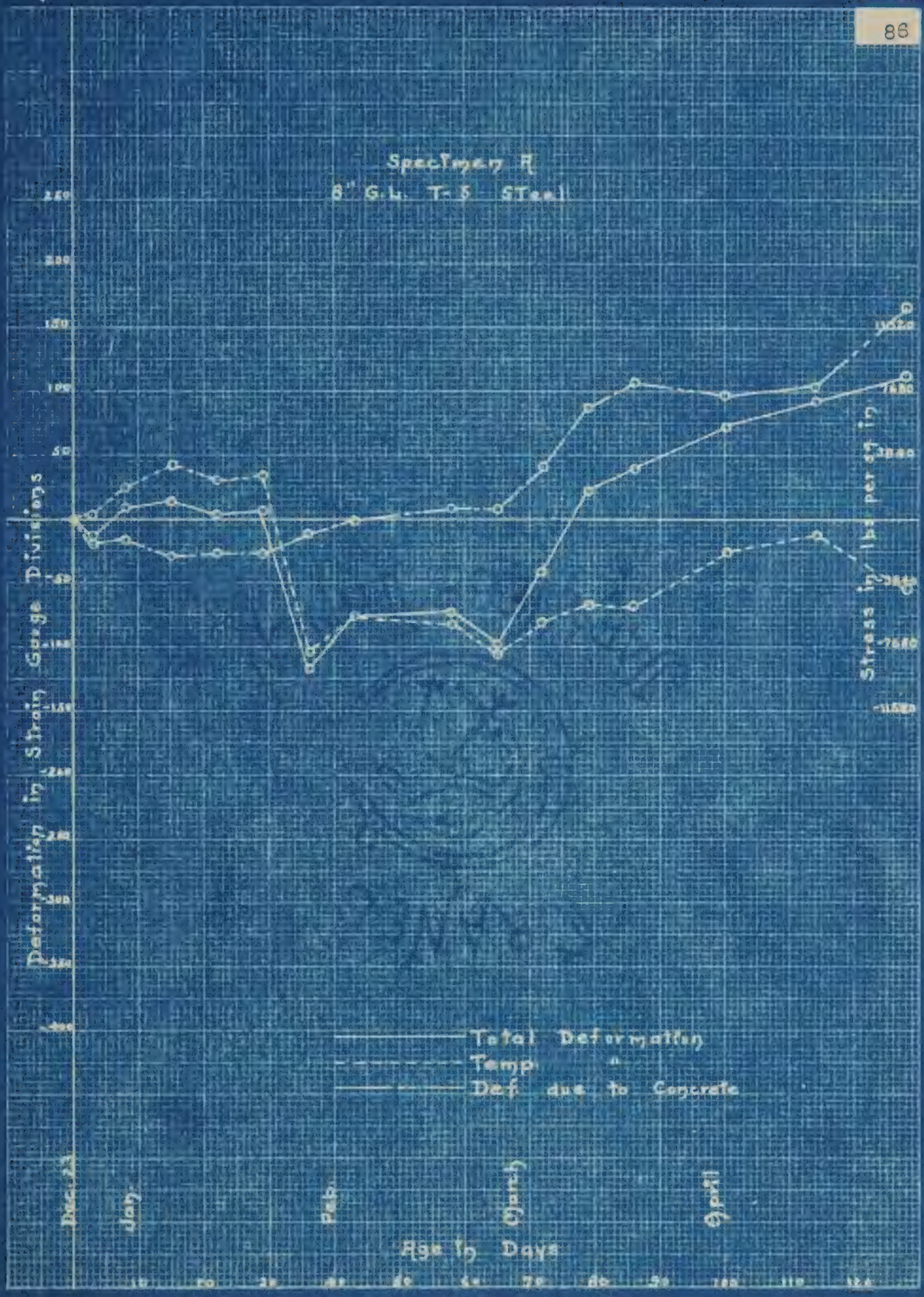

Specimen B
Ames Dial
Ave Curves for 4 center point line B
Total Deformations
Temp.
Moisture and Shrinkage Def
Deformations in Dial Divisions
Feb.
March
April

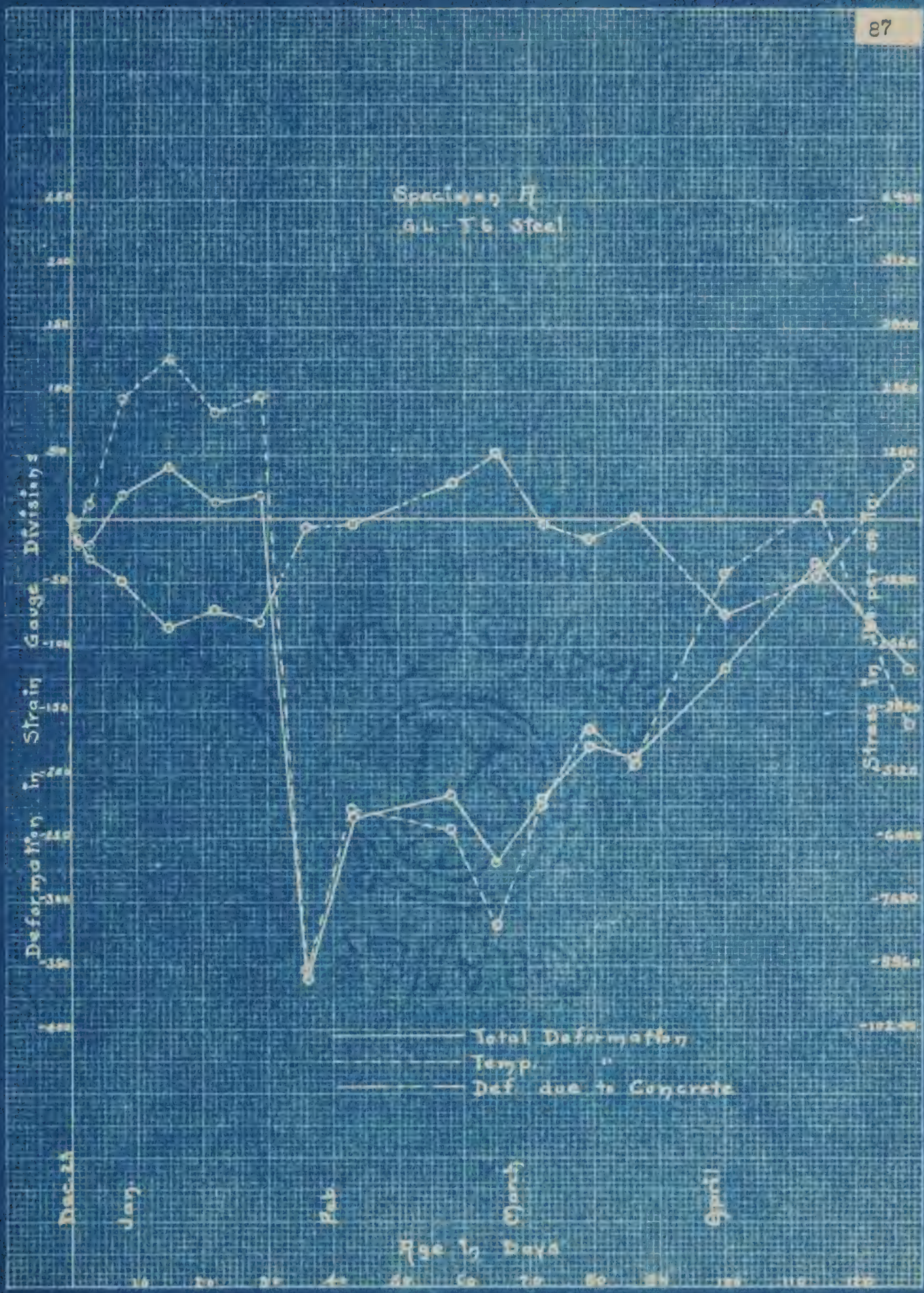

Specimen B
Open Dial
Gr. Curves - Battery
Total Deformation
Temp.
Moisture and Shrinkage Def
Deformations in Dial Divisions
Age in Days
Feb.
March
April

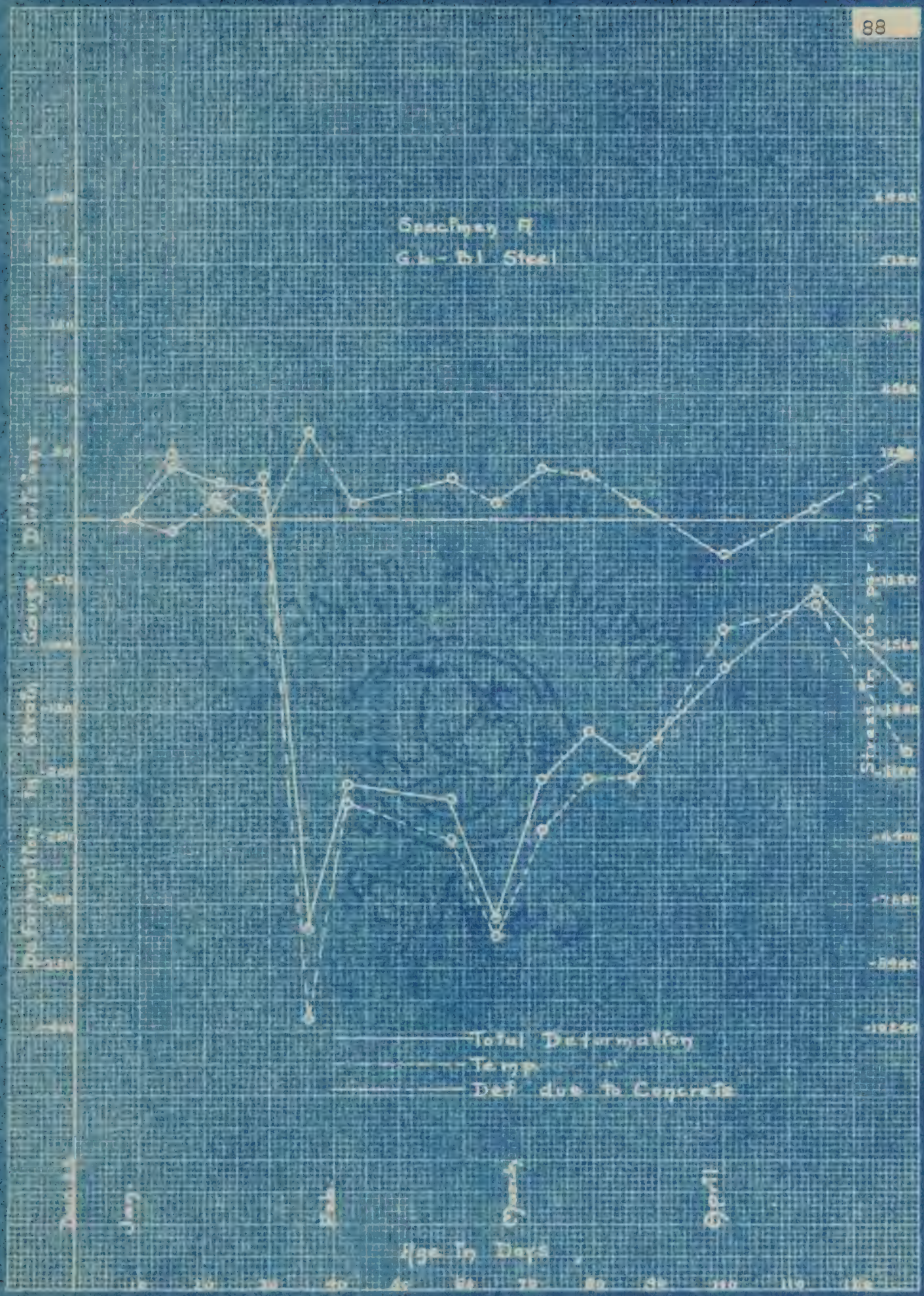
Specimen A
G.L.-T1 Steel
Deformation in Strain Gauge Divisions
Stress in Pounds per Sq. In.
Total Deformation
Temp.
Def. due to Comp.
Dec. 20
Jan.
Feb.
March
April
Age in Days

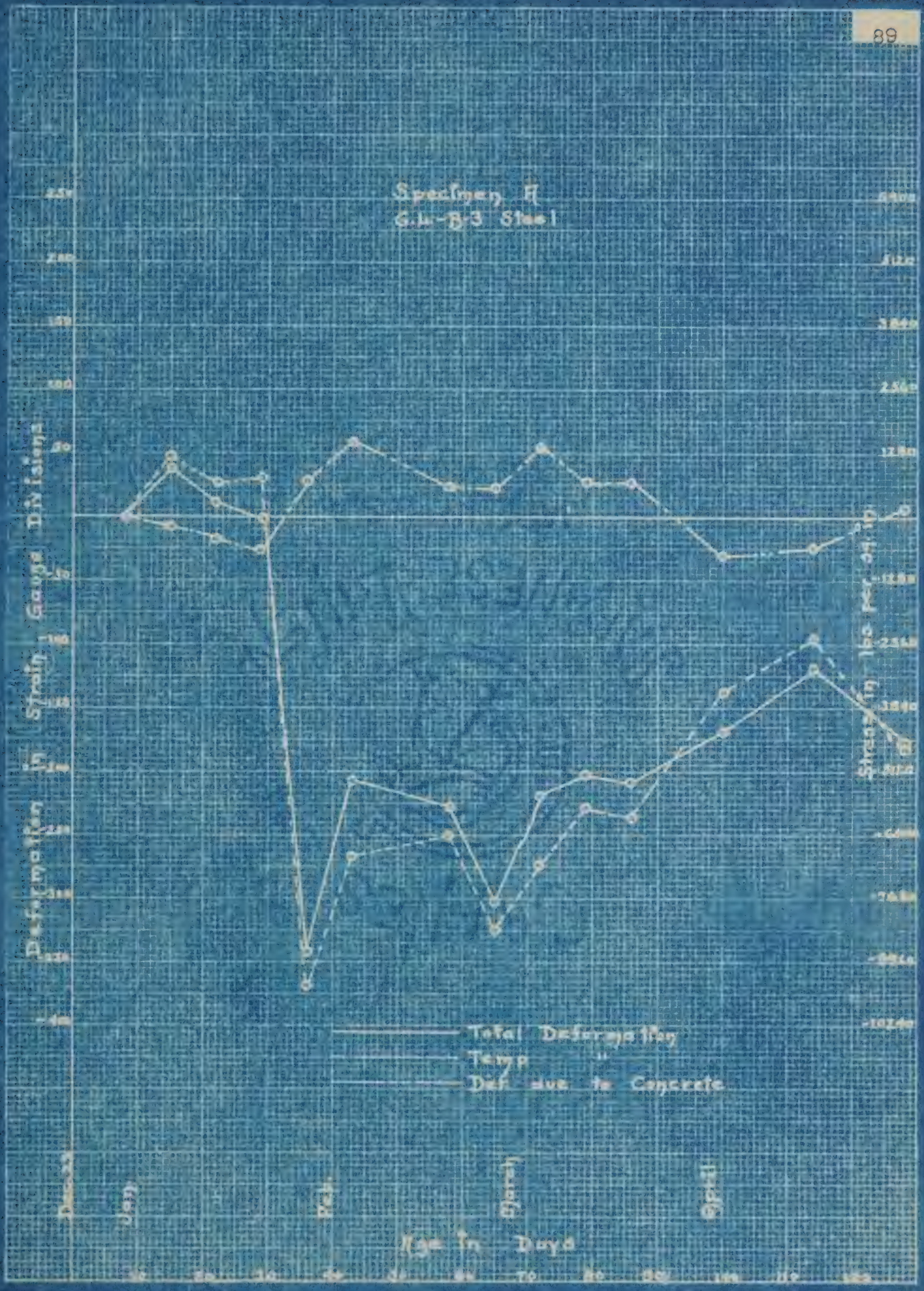

Specimen A
G.W.- T3 Steel
Deformation in Strain Gauge Divisions
Stress in lbs. per sq. in.
Total Deformation
Temp. "
Def. due to Concrete
Dec. 28
Jan.
Feb.
March
April
Age in Days

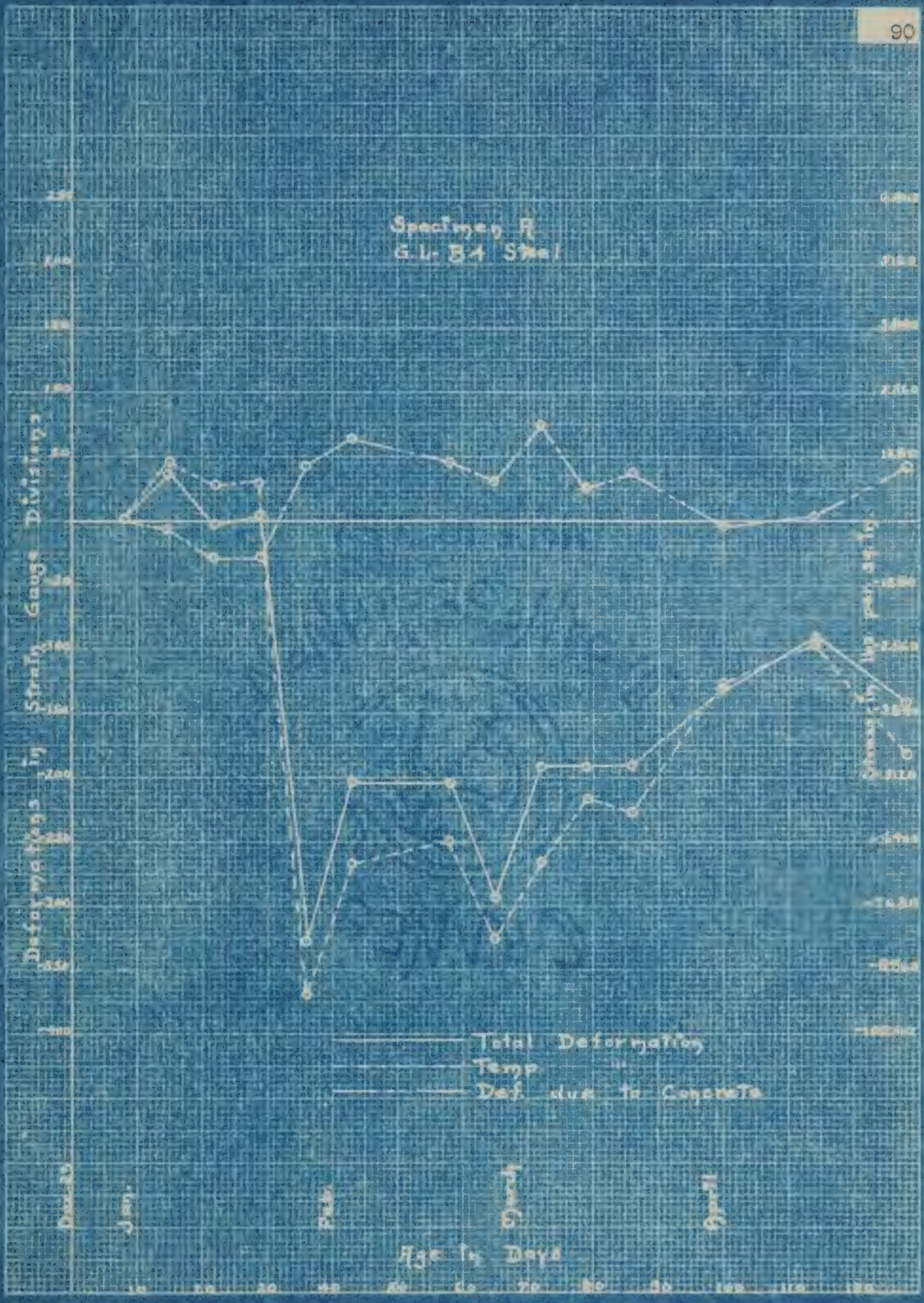

Specimen F
Grade T 4 Steel
Deformation by Strain Gauge Divisions
Stress in Lb. per sq. in.
Total Deformation
Temp "
Def due to Concrete
Dec 14
Jan
Feb
March
April
Age in Days

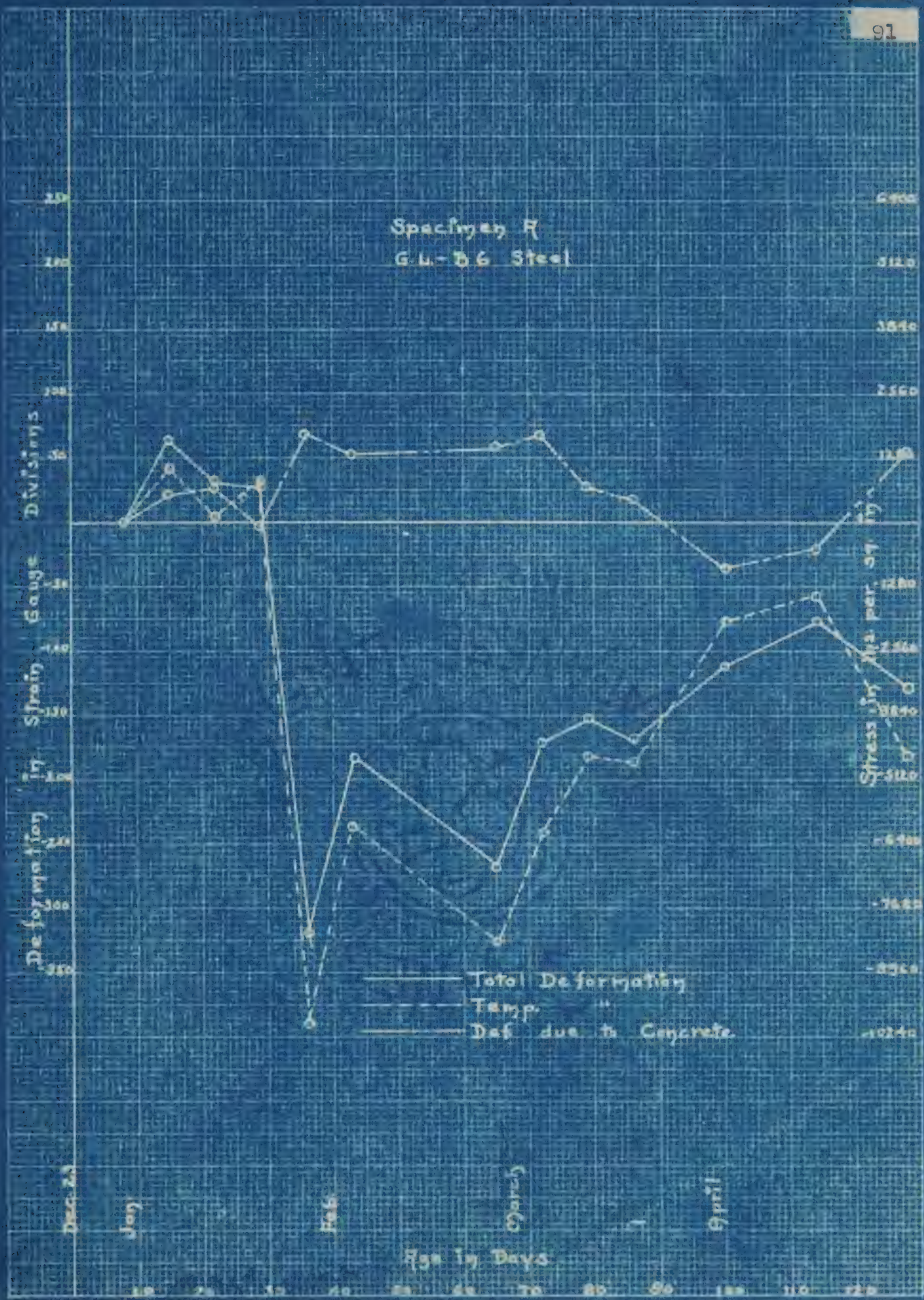

Specimen R
8" G.L. T-S Steel
Deformation in Strain Gauge Divisions
Stress in lbs per sq in.
Total Deformation
Temp. "
Def due to Concrete
Dec 23
Jan.
Feb.
March
April
Age in Days

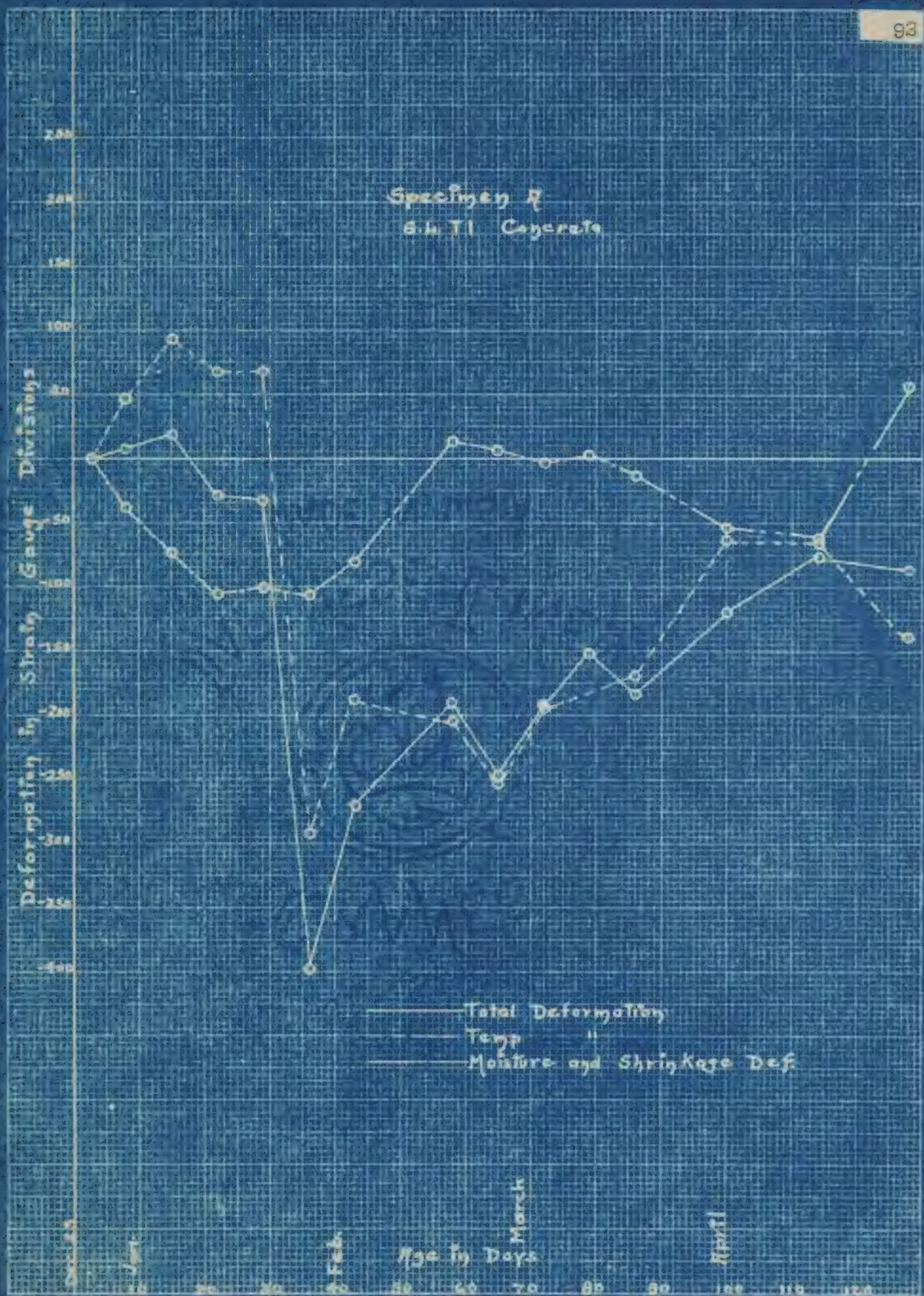

Specimen A
G.L. - T.S. Steel
Deformation in Strain Gauge Divisions
Stress in Lbs. per sq. in.
Total Deformation
Temp. "
Def. due to Concrete
Dec. 14
Jan.
Feb.
March
April
Age in Days

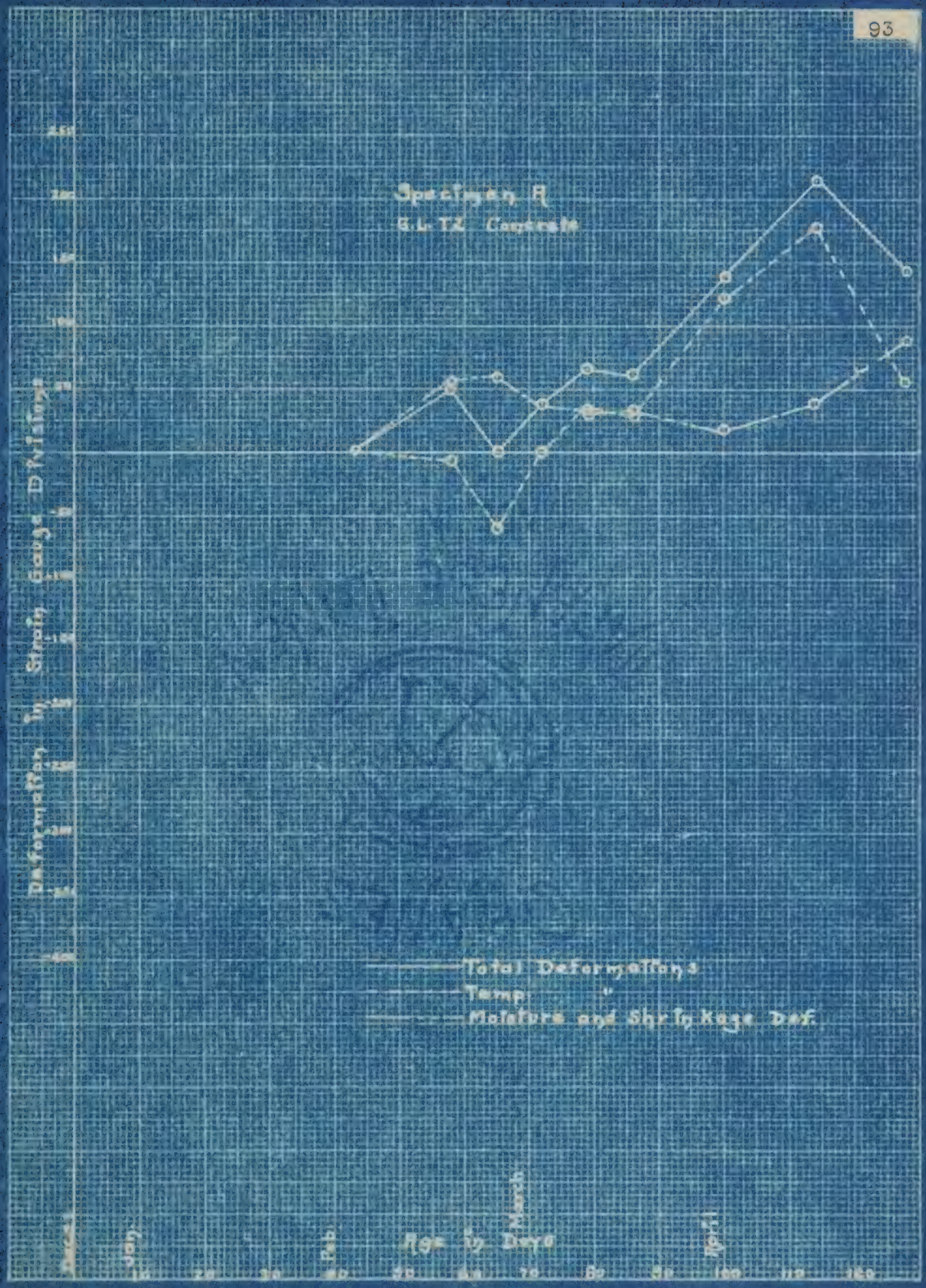

Specimen A
Total Deformation
Temp
Def due to Concrete
Stress in lbs per sq in
Deformation in (Gauge) Divisions
Jan
Feb
March
April
Age in Days

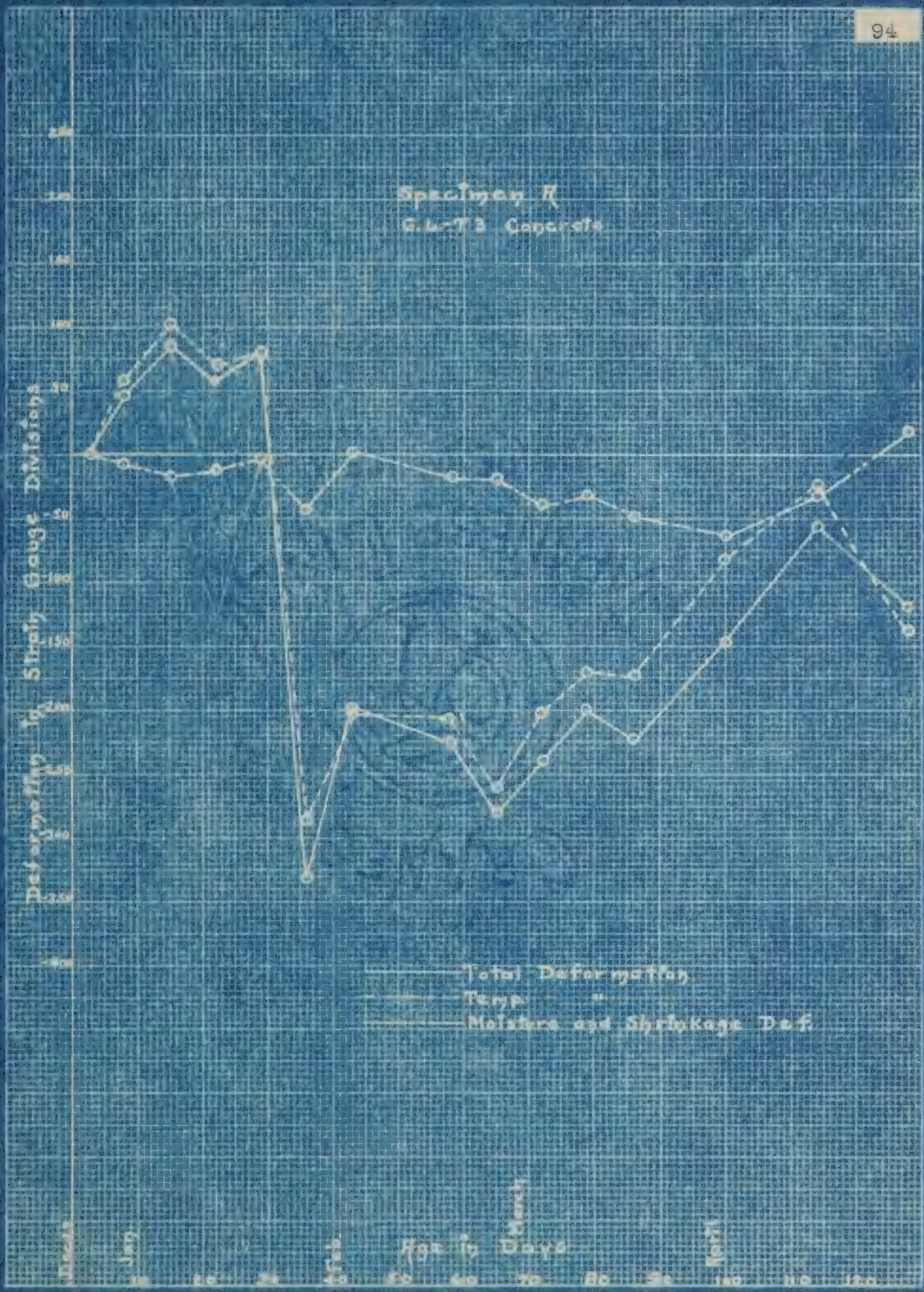

Specimen H
G.L-B-3 Steel
Deformation in Strain Gauge Div Units
Stress in lbs per sq in
Total Deformation
Temp "
Def due to Concrete
Age in Days
Jan
Feb
March
April

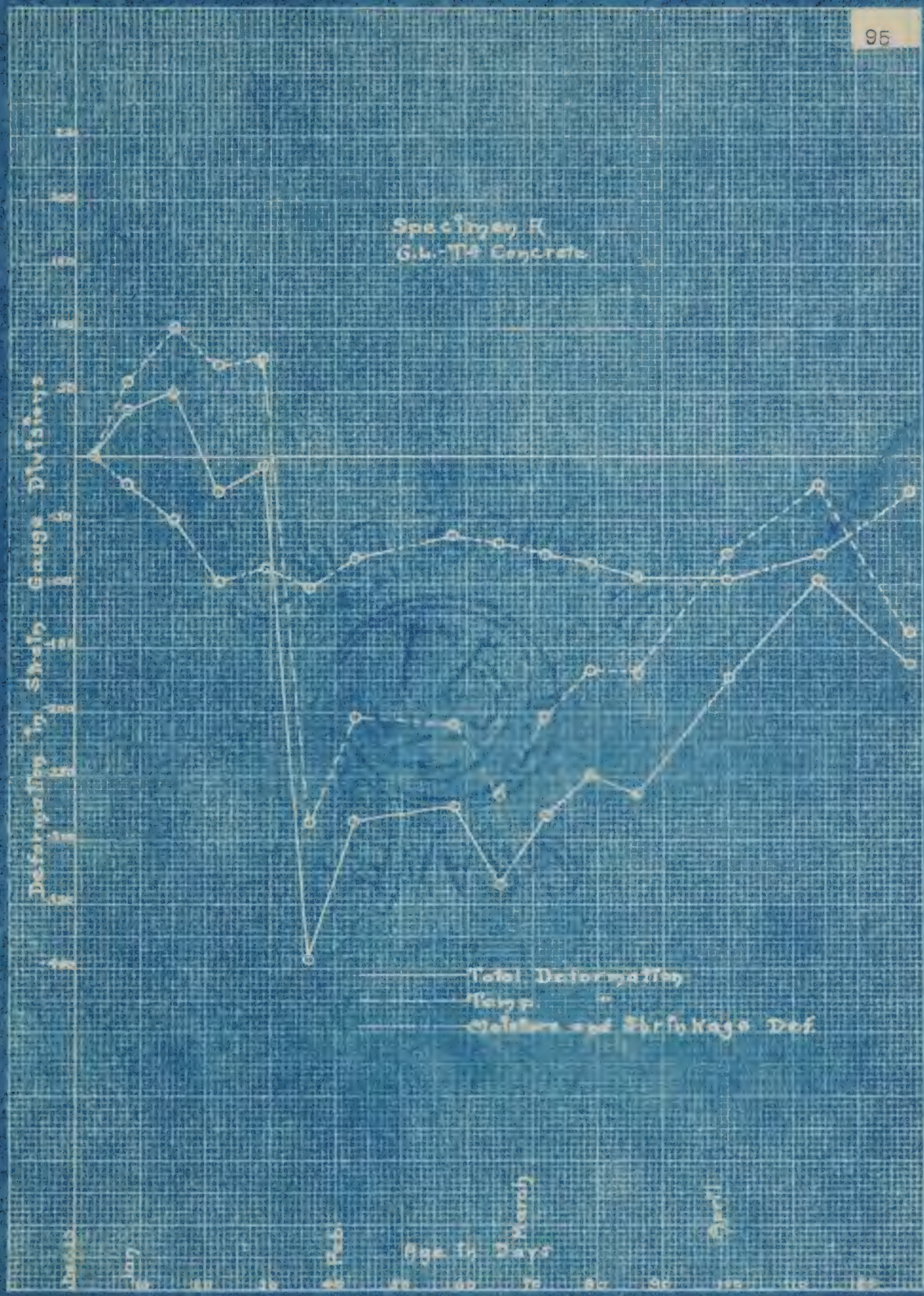

Specimen A
G.L. B4 Steel
Total Deformation
Temp "
Def. due to Concrete
Jan.
Feb.
Mar.
Apr.
Age in Days

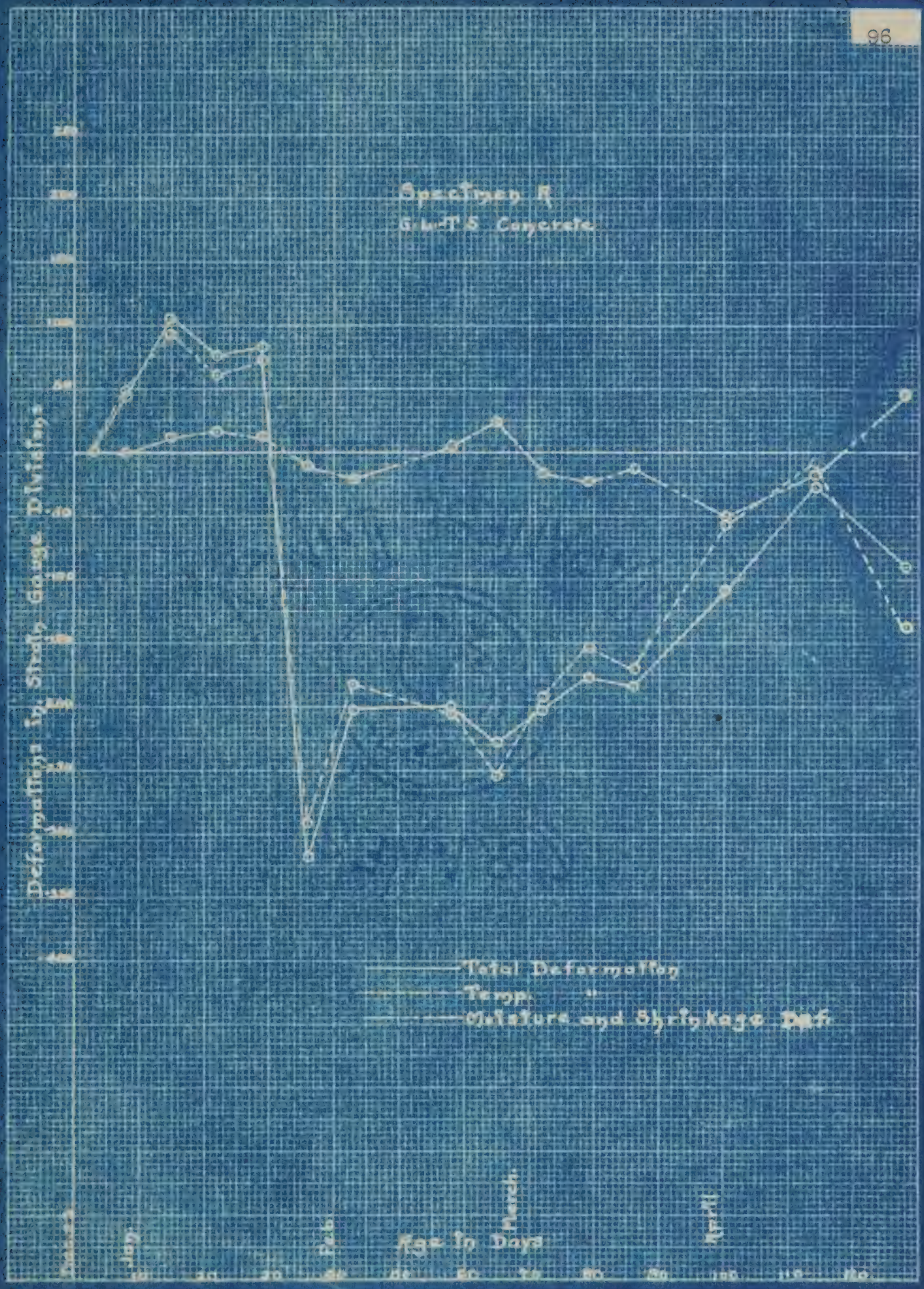

Specimen A
G.L.-B.6 Steel
Deformation in Strain Gauge Divisions
Stress in Lbs. per Sq. In.
Total Deformation
Temp. "
Def. due to Concrete
Dec. 23
Jan.
Feb.
March
April
Age in Days

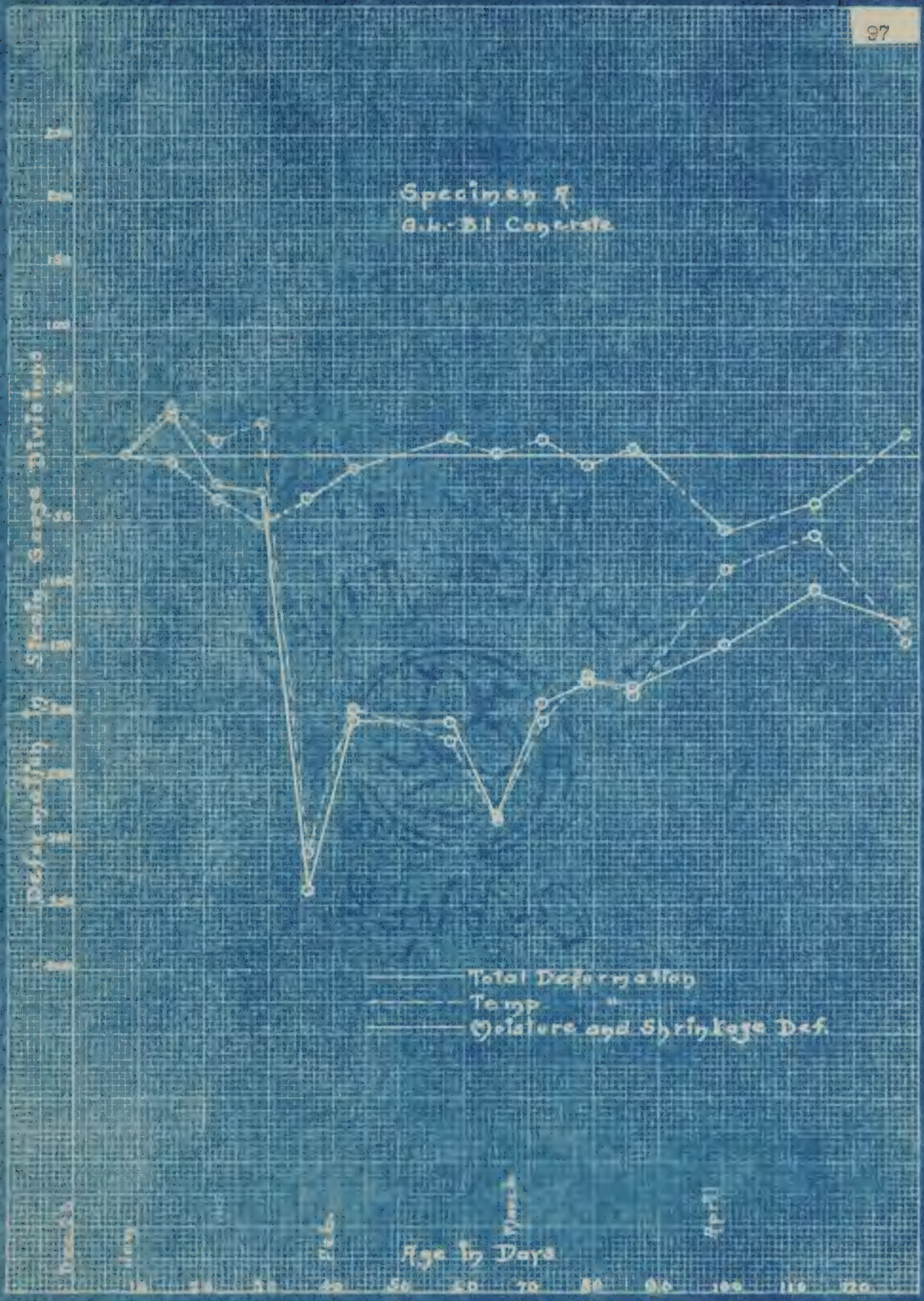

Specimen R
6.4.T.1 Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

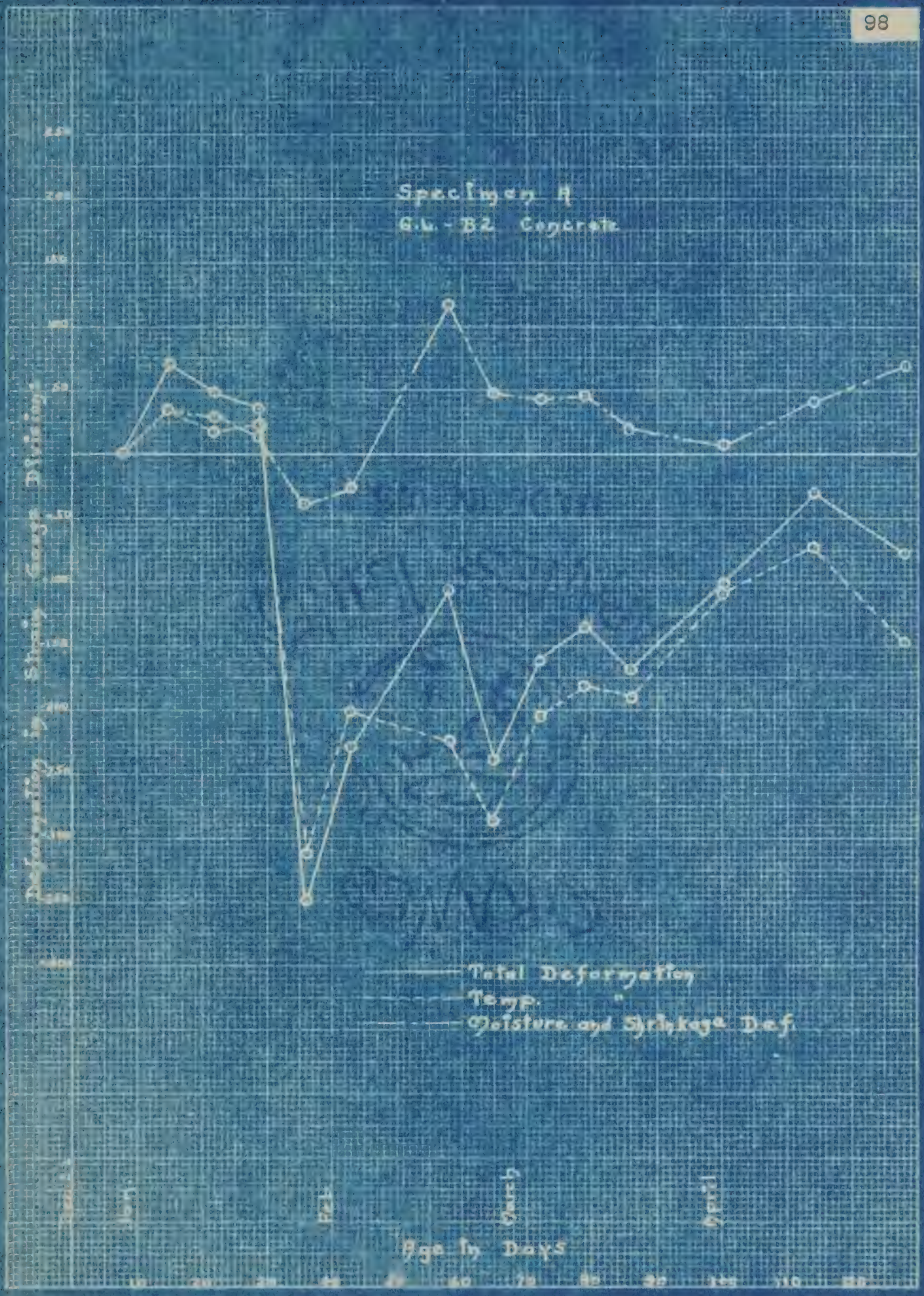

Specimen A
G.L. TZ Concrete
Total Deformations
Temp. "
Moisture and Shrinkage Def.
Jan.
Feb.
March
April
Age in Days

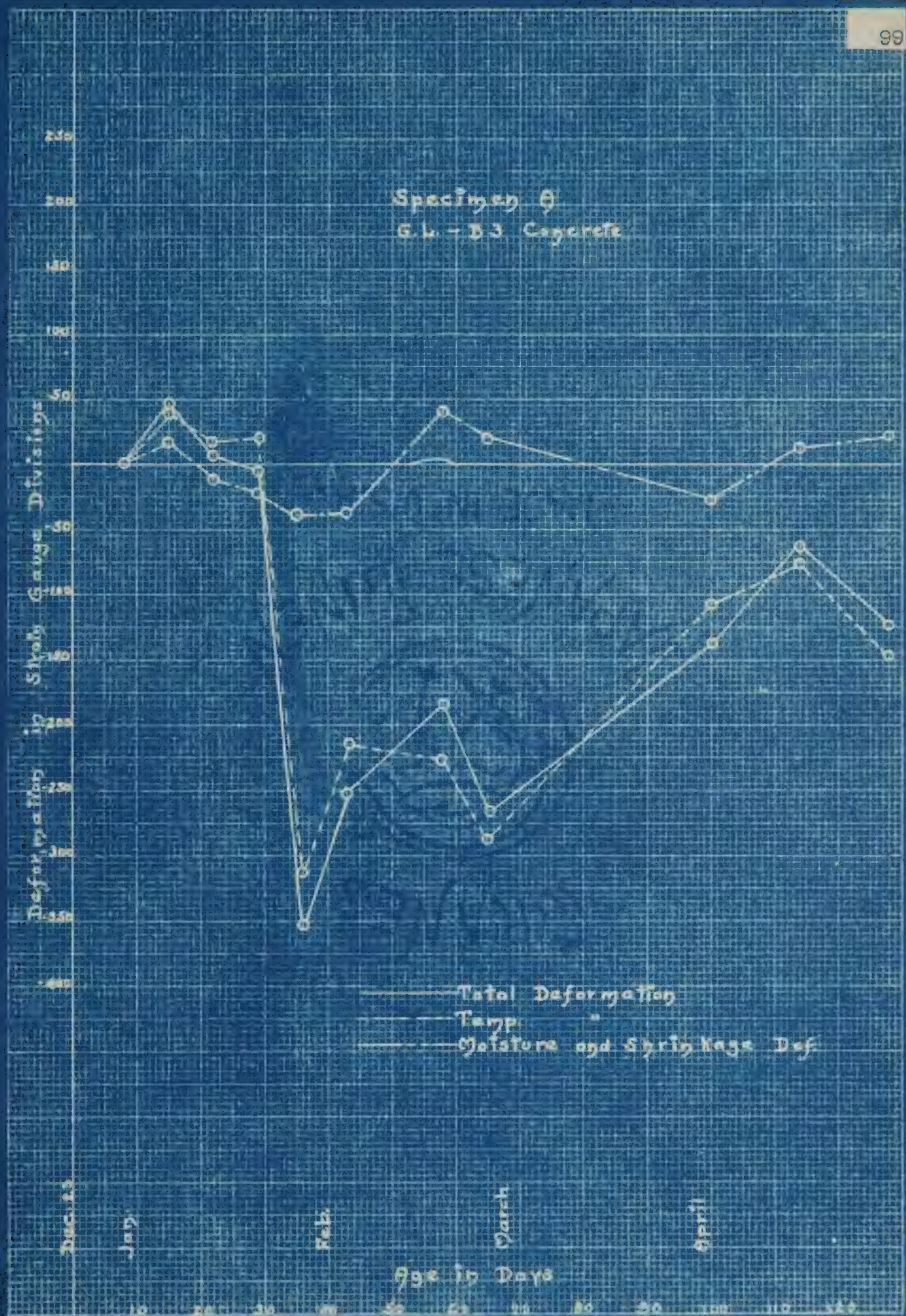

Specimen R
G.L.-73 Concrete
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Specimen K
G.L.-T4 Concrete
Deformation in Shade Gauge Divisions
Total Deformation
Temp F
Creep and Shrinkage Def.
Age in Days
Jan
Feb
March
April

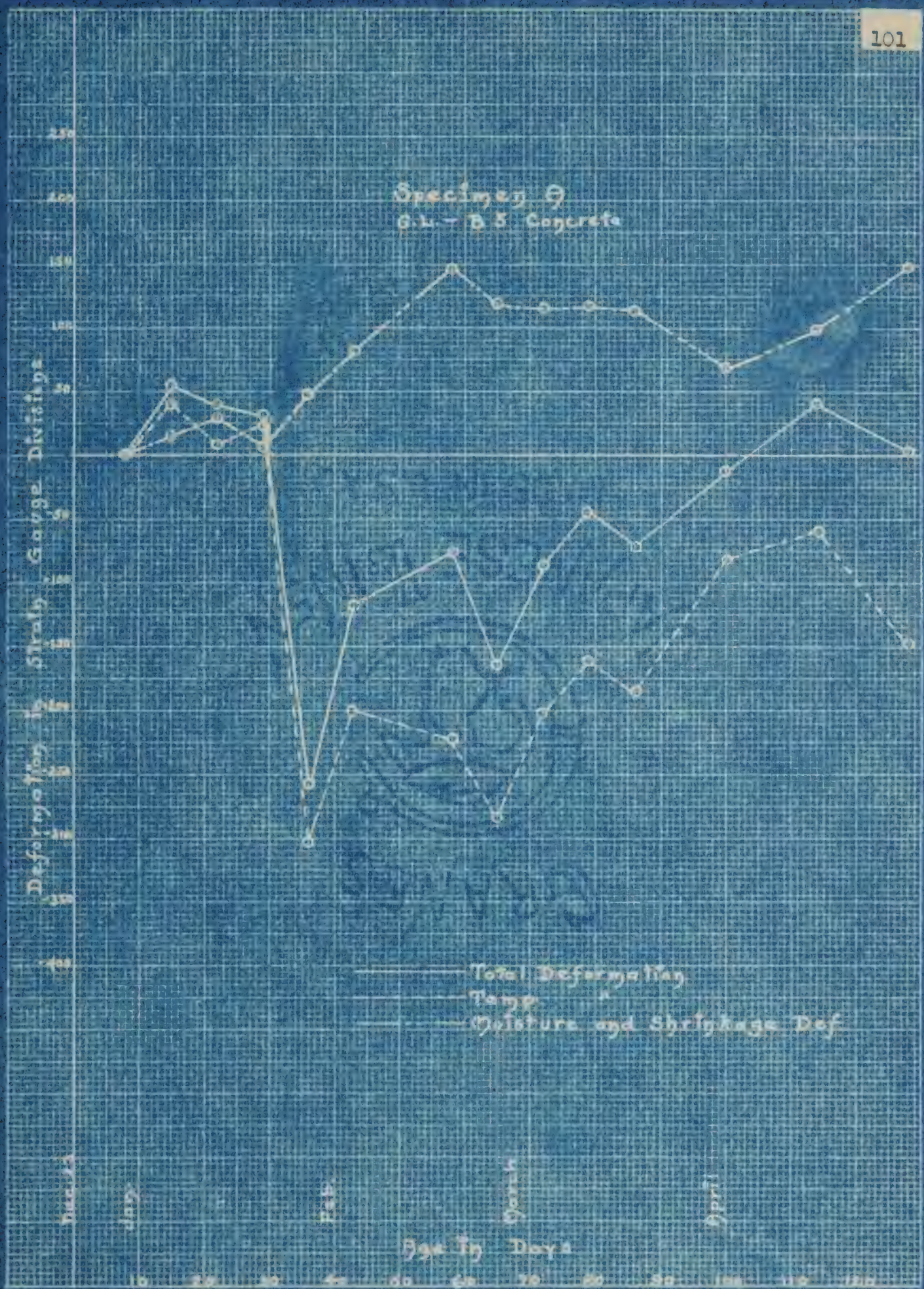

Specimen R
G-M-T-S Concrete
Total Deformation
Temp.
Moisture and Shrinkage Diff.
Jan.
Feb.
March
April
Age in Days

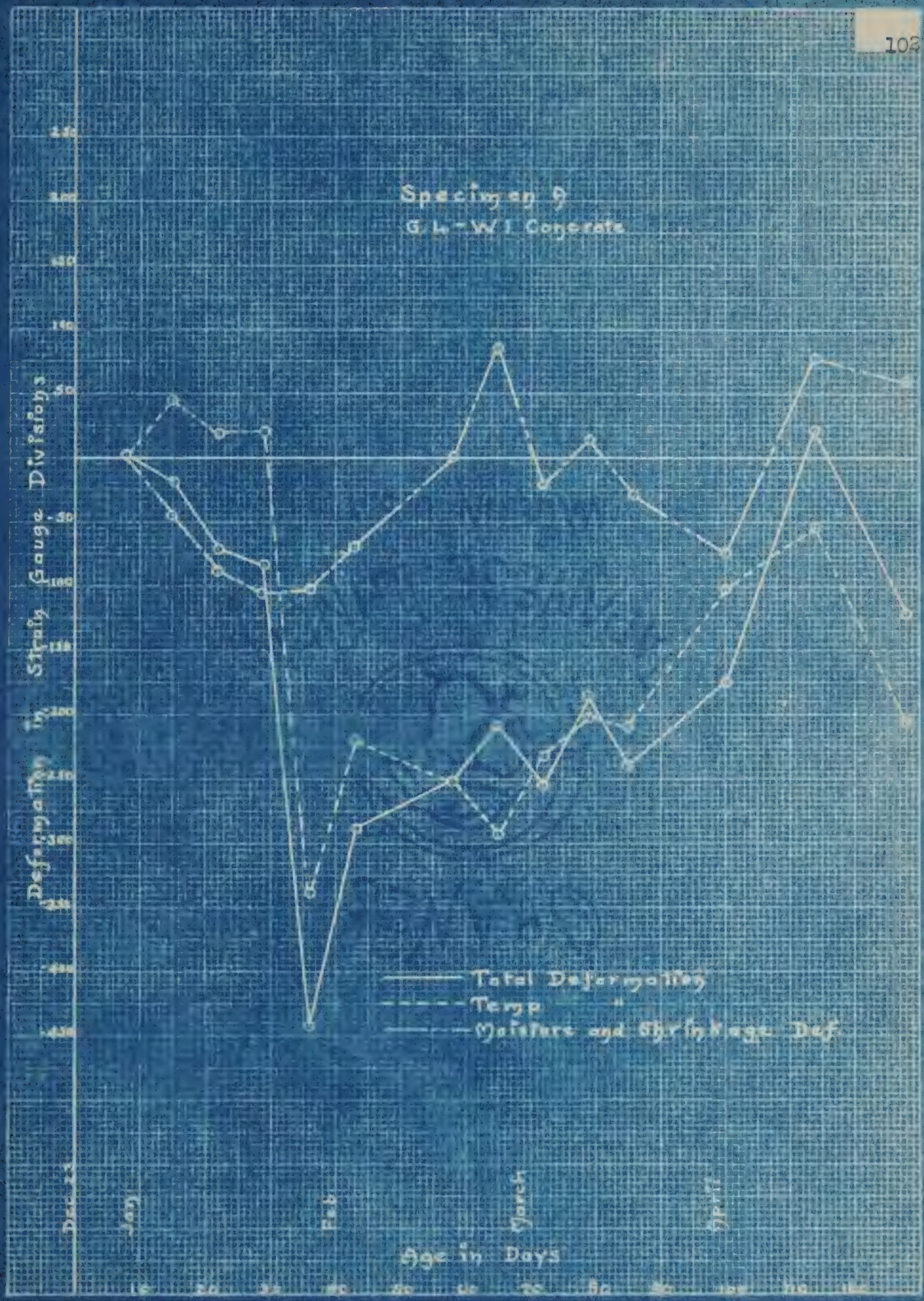

Specimen R
6.4.-3.1 Concrete
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Age in Days
Feb.
March
April

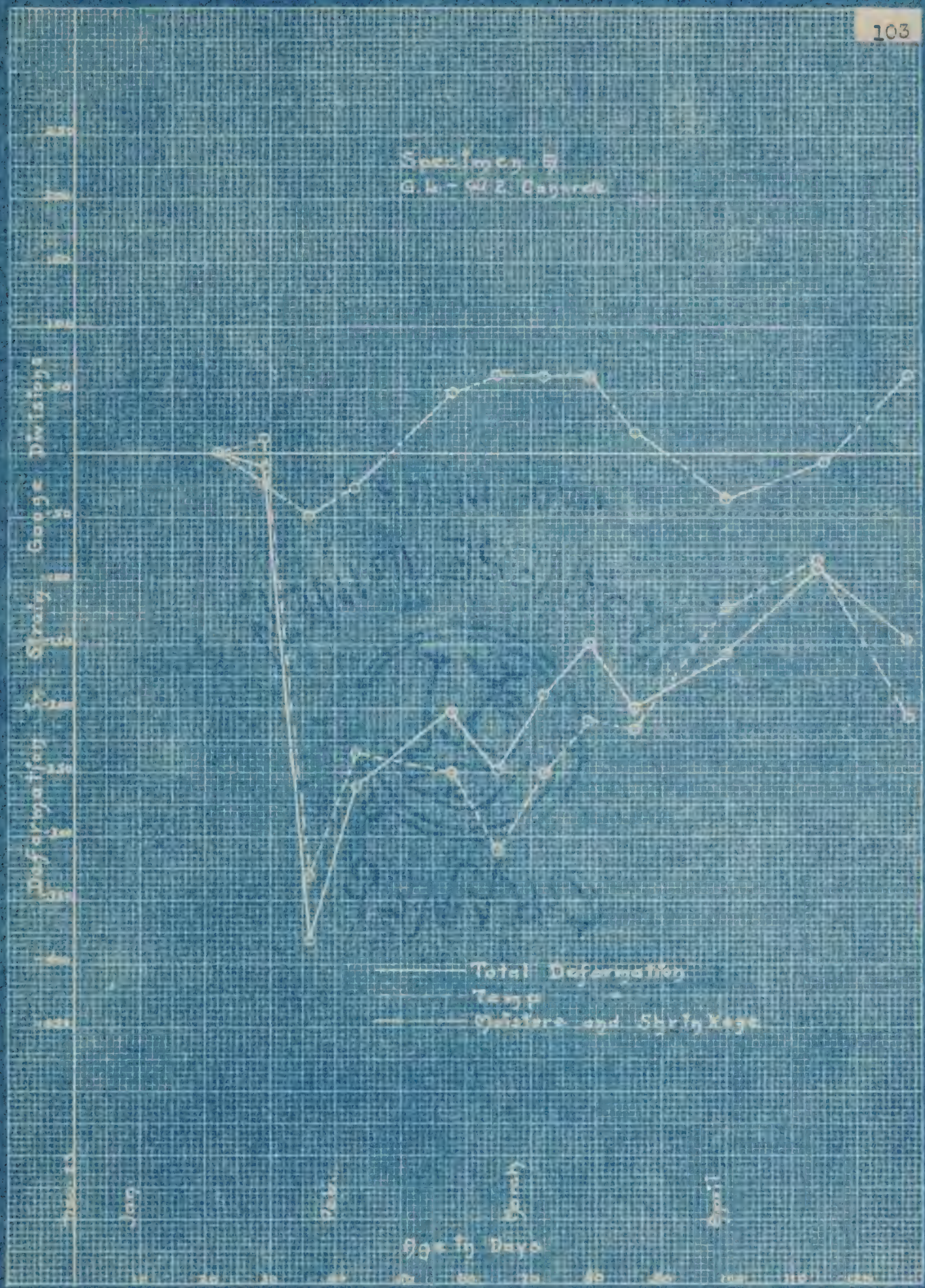

Specimen A
G.L. - B2 Concrete
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Deformation in 1/1000 Inches Strain Gauge Division
Age in Days
April


Specimen 9
G.L. - B.3 Concrete
Deformation in Shock Gauge Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def.
Dec. 28
Jan.
Feb.
March
April
Age in Days

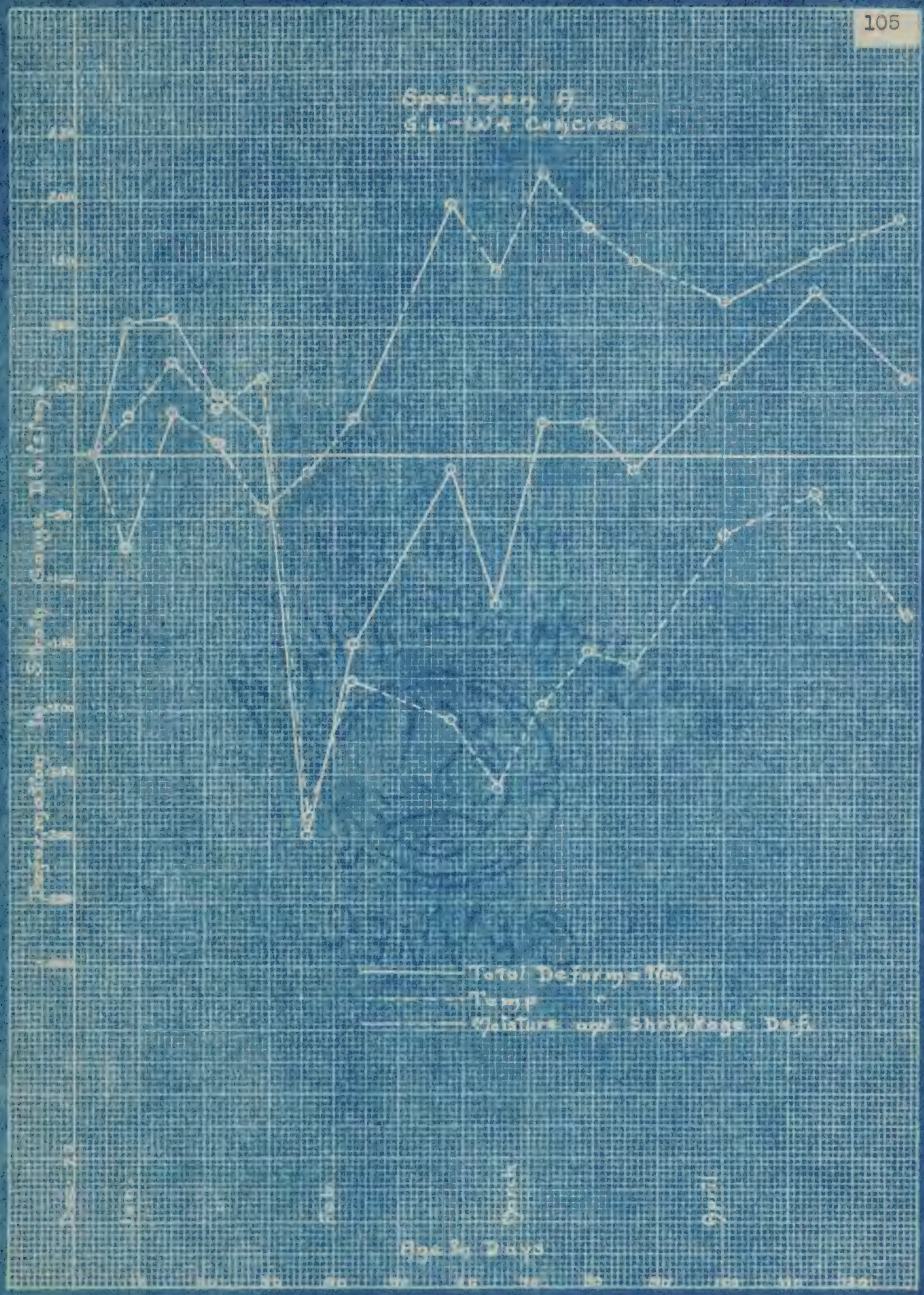
Specimen 8
G.L. - B.4 Concrete
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformation in Strain Gauge Divisions
Age in Days
Feb.
Jan.
Mar.
April

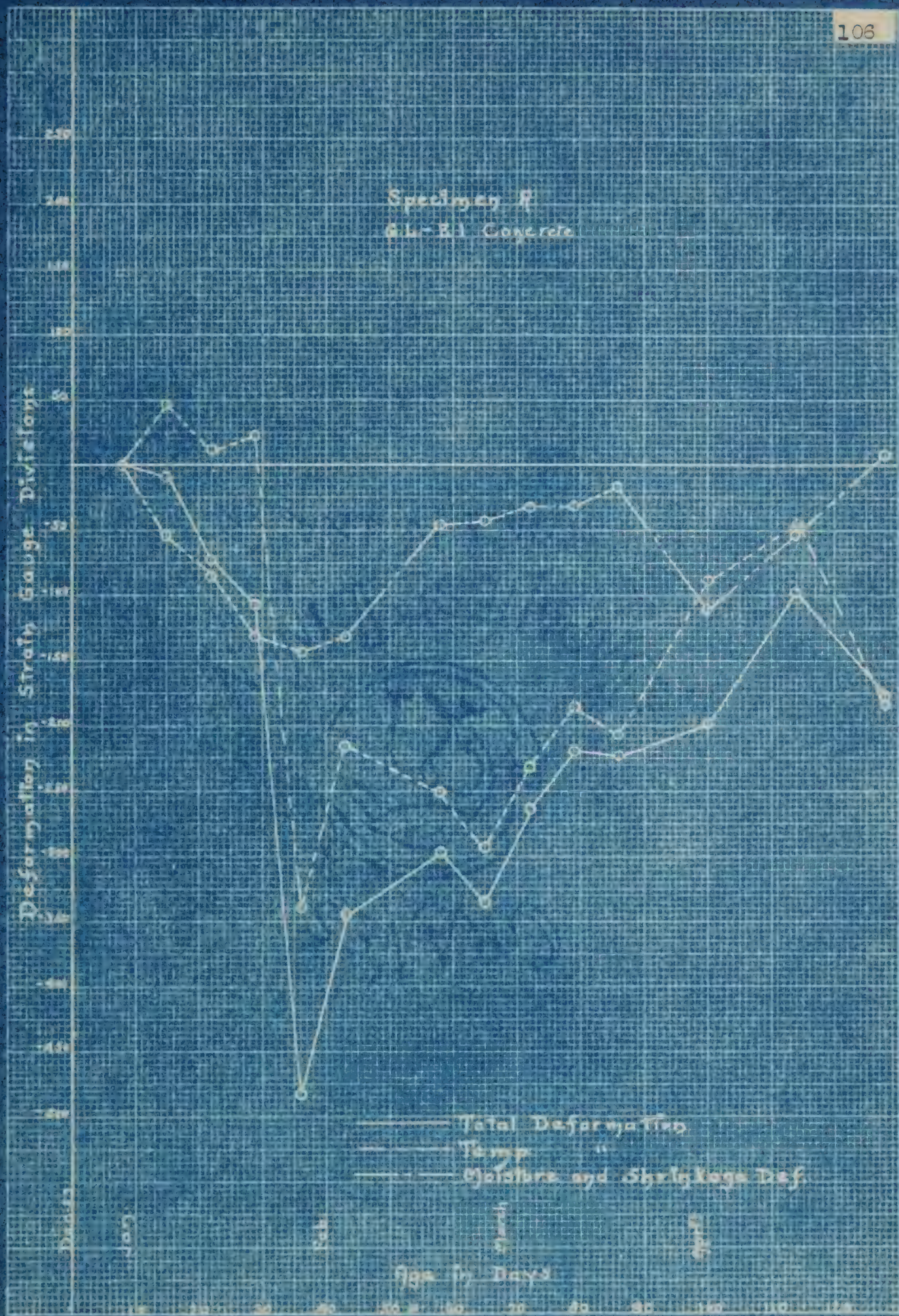

Specimen 9
G.L. - B 5 Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days
Jan.
Feb.
March
April

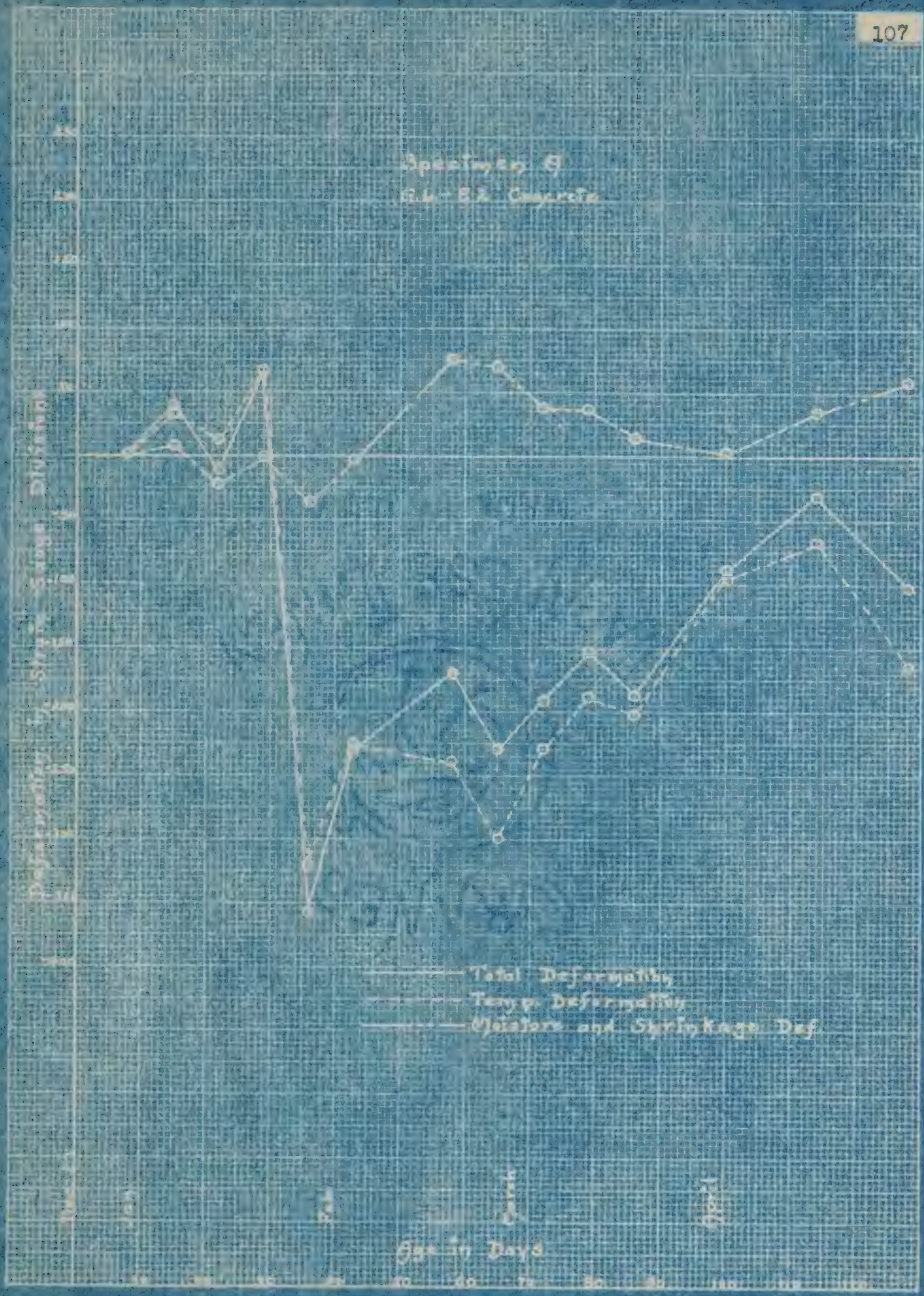

Specimen 9
G L - W 1 Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp "
Moisture and Shrinkage Def.
Dec 22
Jan
Feb
March
April
Age in Days

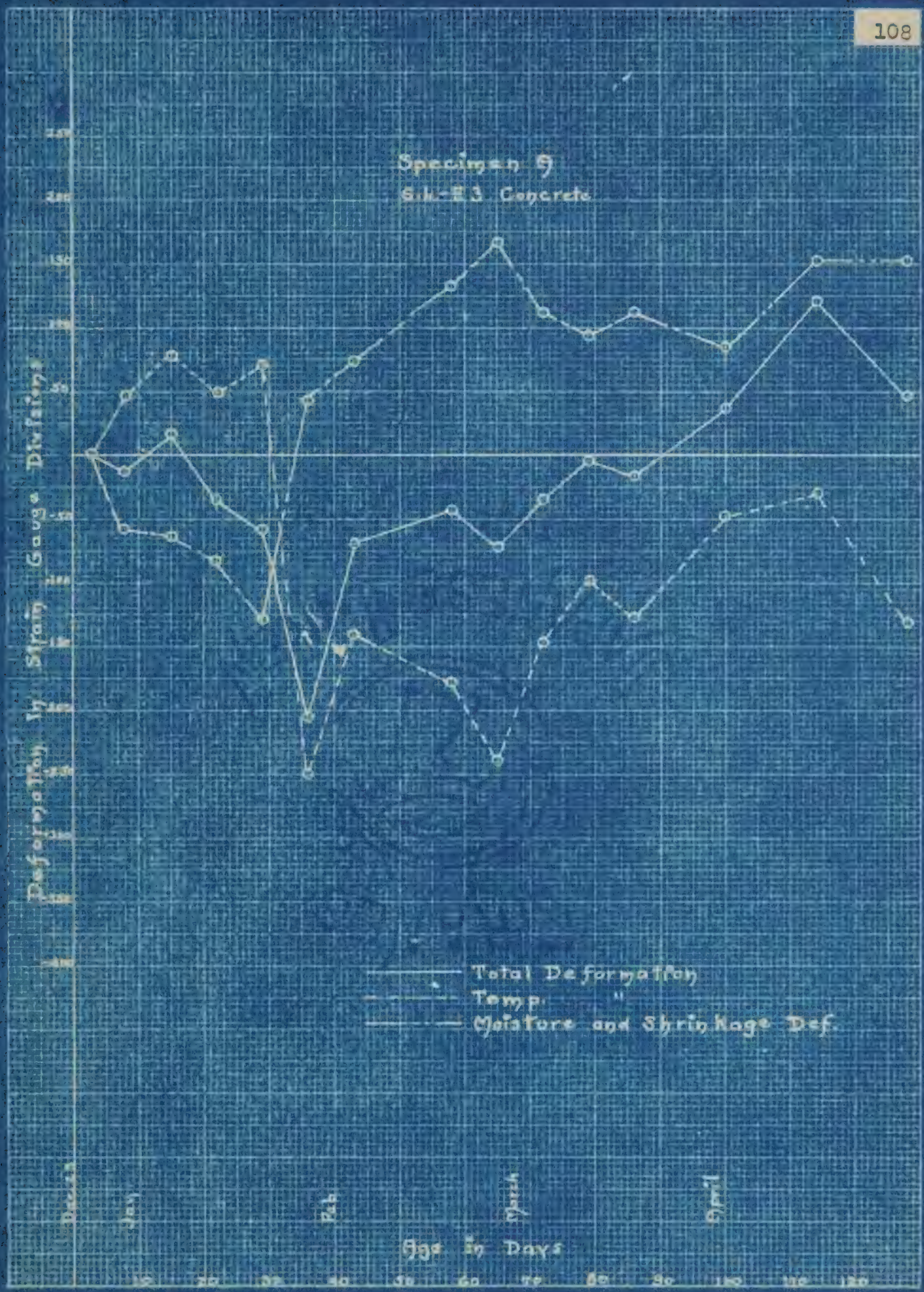

Specimen 5
G.W. - 92 2. Gayrede
Deformation by Strain Gauge Deviation
Total Deformation
Temp.
Moisture and Shrinkage
Jan.
Feb.
March
April
Age in Days

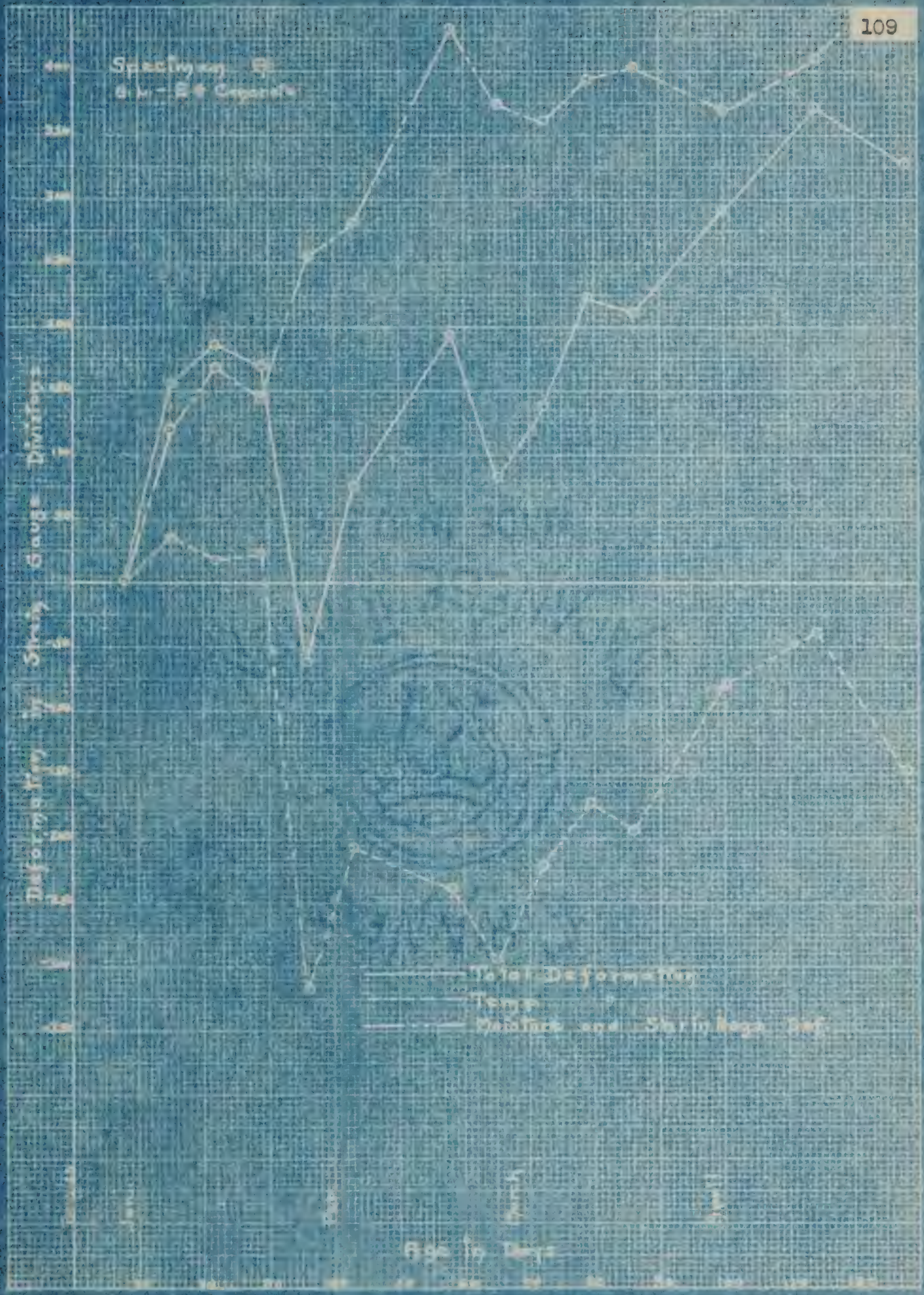
Specimen 9
G.L.W.I. Concrete
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days

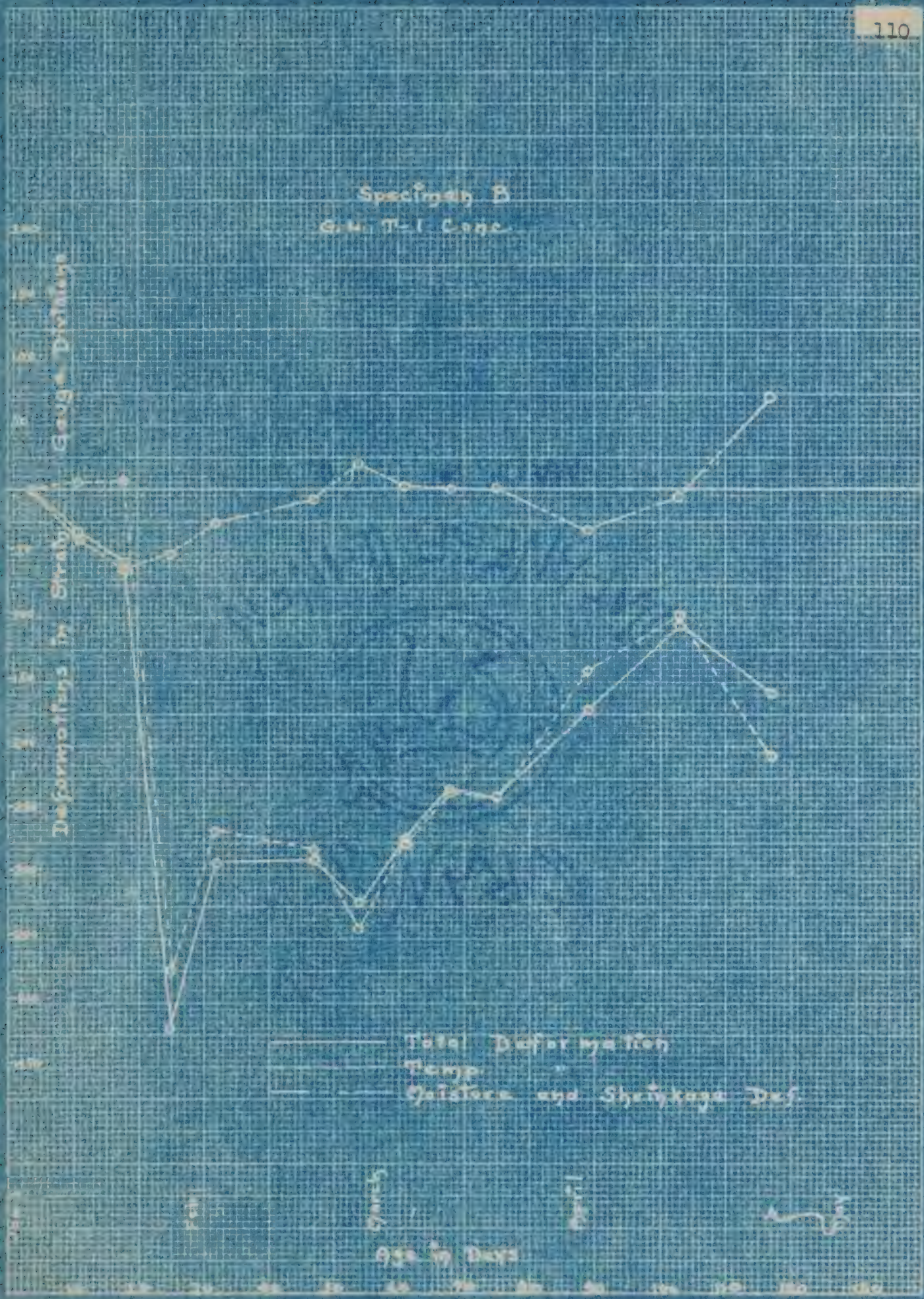

Specimen 8
6 L-D14 Concrete
Total Deformation
Temp
Moisture and Shrinkage Def.
Age in Days

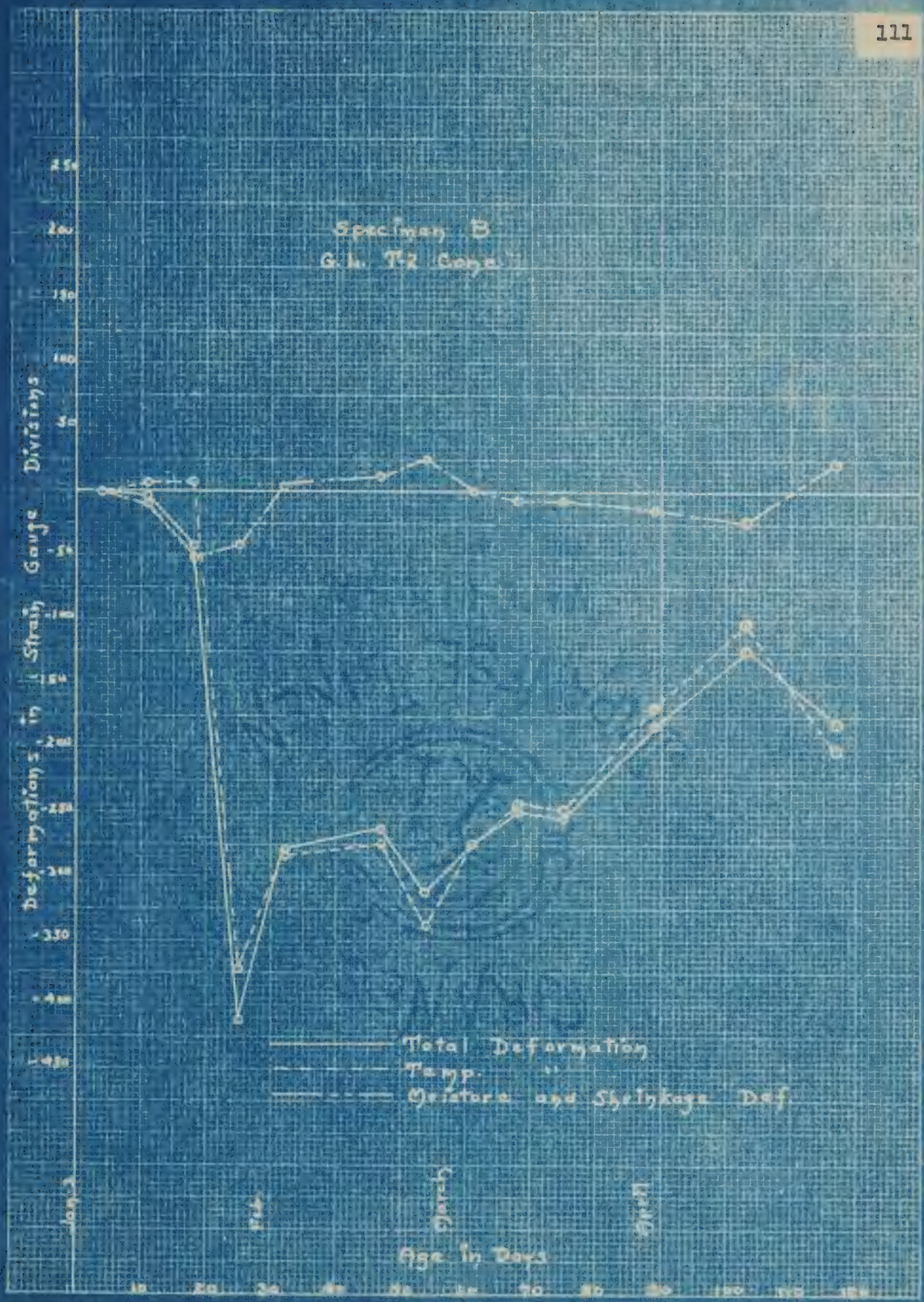

Specimen A
6lb-Bl Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp
Moisture and Shrinkage Def
Age in Days

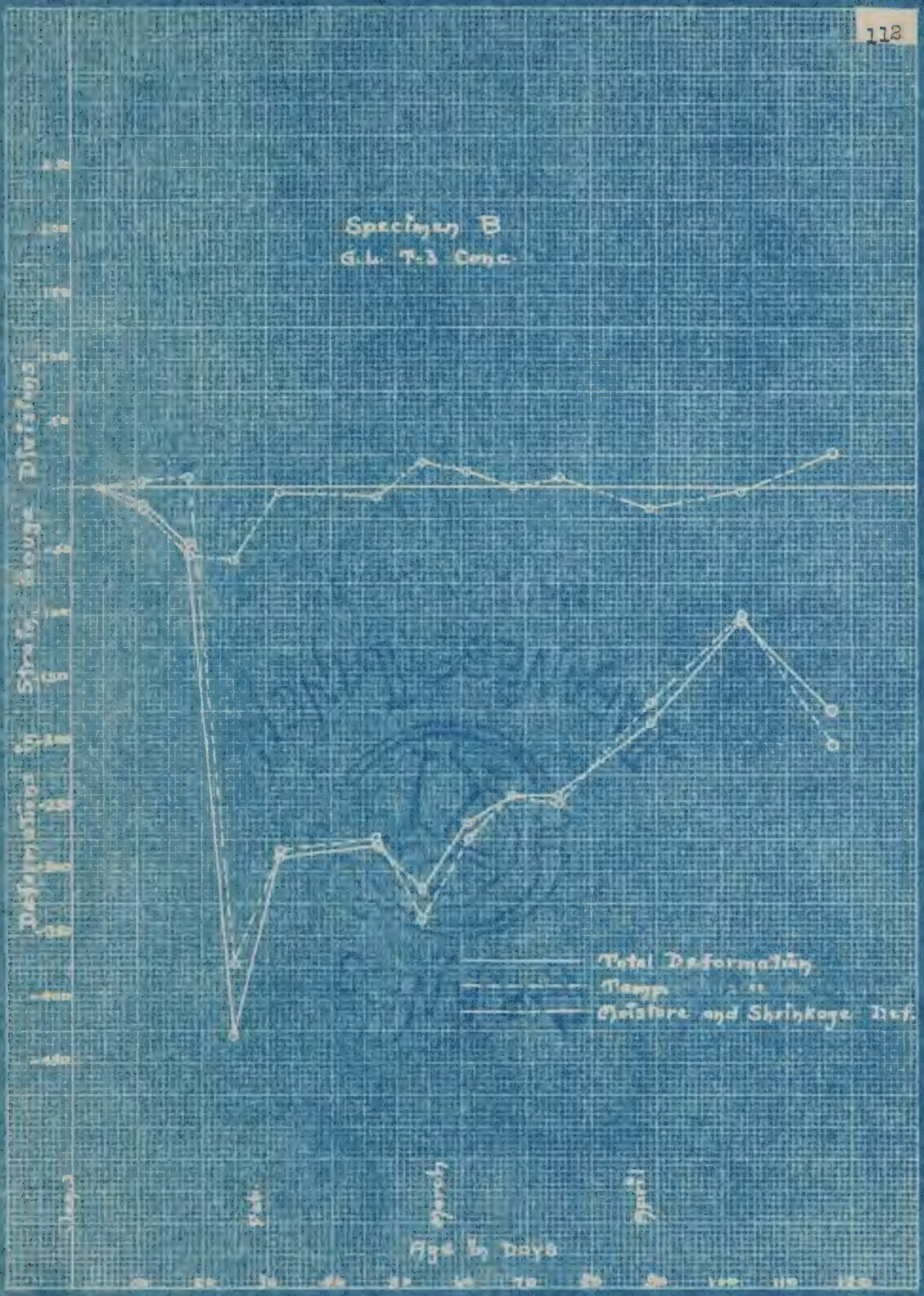

Specimen 9
Total Deformation
Temp. Deformation
Moisture and Shrinkage Def.
Age in Days

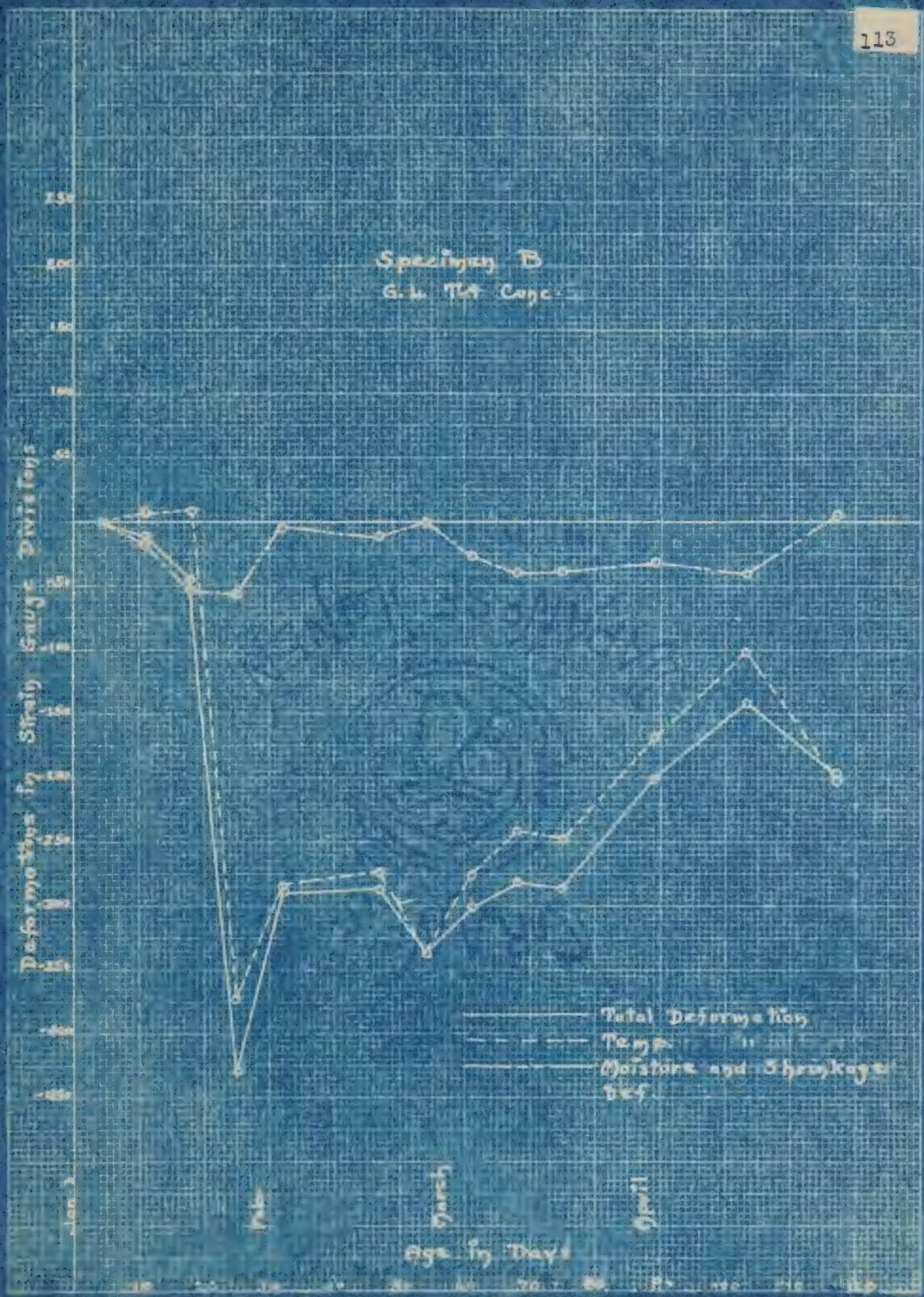

Specimen 9
Silk-E3 Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Feb
March
April
Age in Days

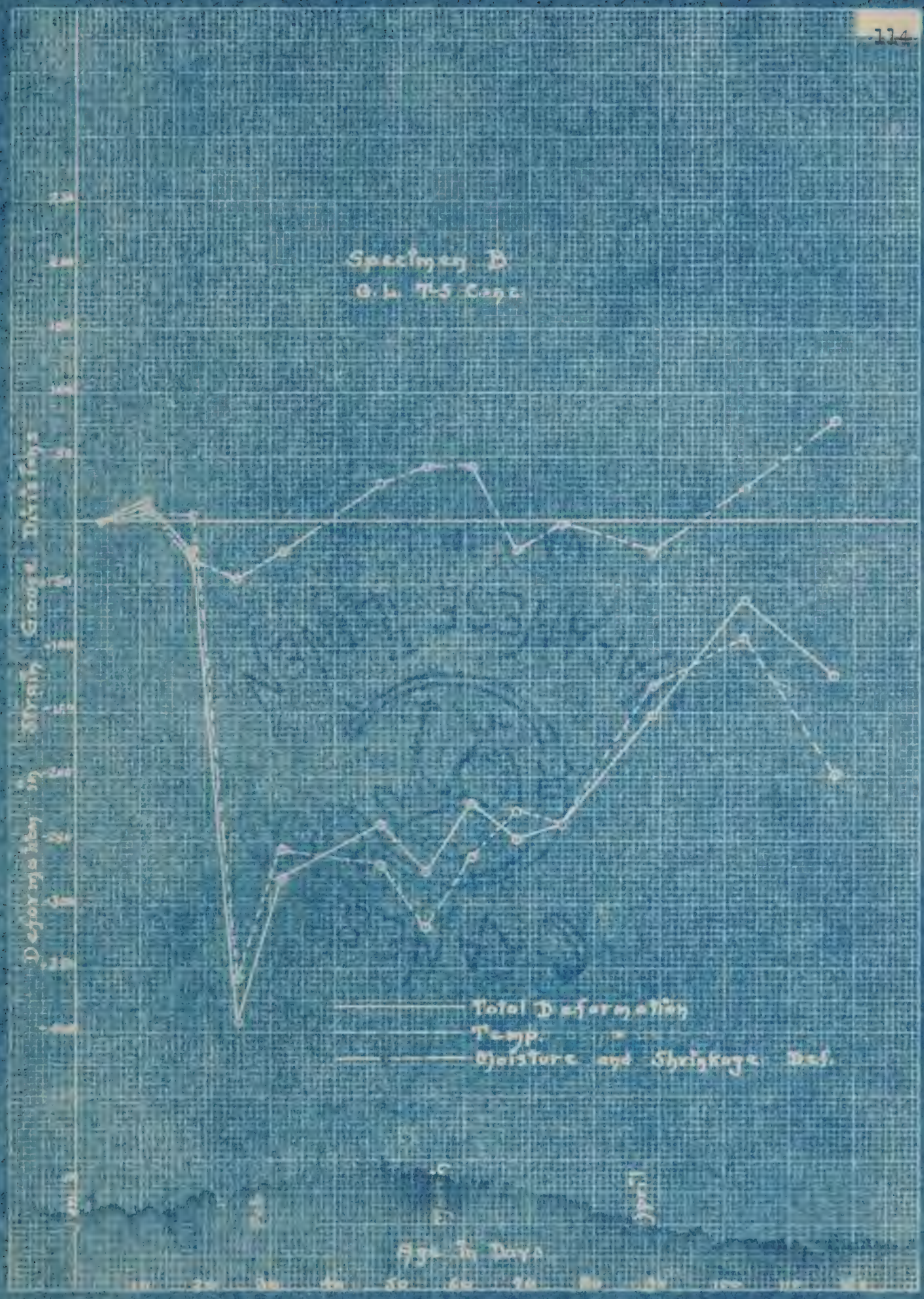

Specimen 9
Deformation by Strain Gauge Division
Total Deformation
Creep
Volume and Shrinkage Def.
Age in Days

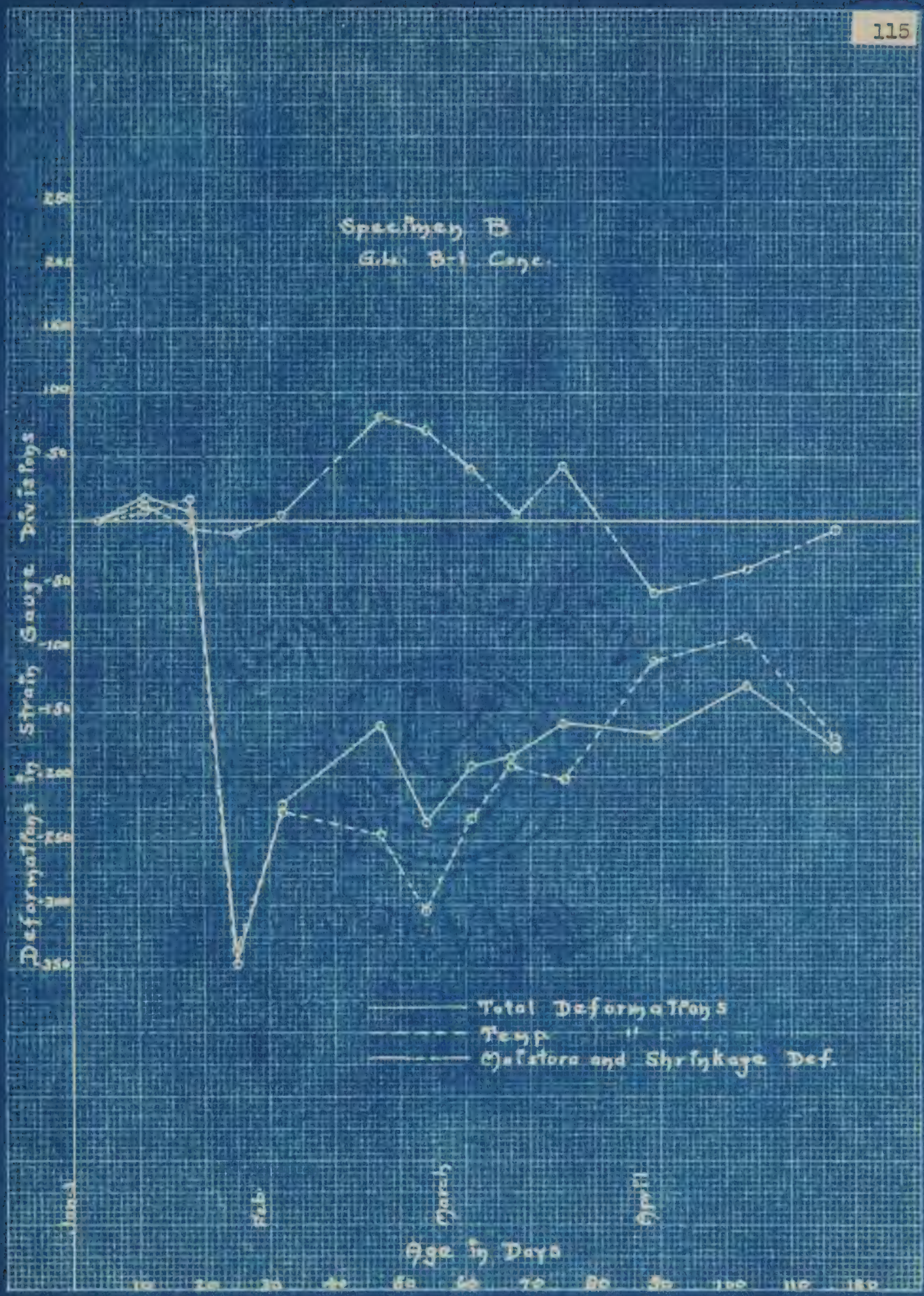

Specimen B
Total Def. per Inch
Resistance and Shrinkage Def.
Age in Days


Specimen B
G.L. T.2 Gage
Deformation in Strain Gauge Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def
Jan.
Feb.
March
April
Age in Days

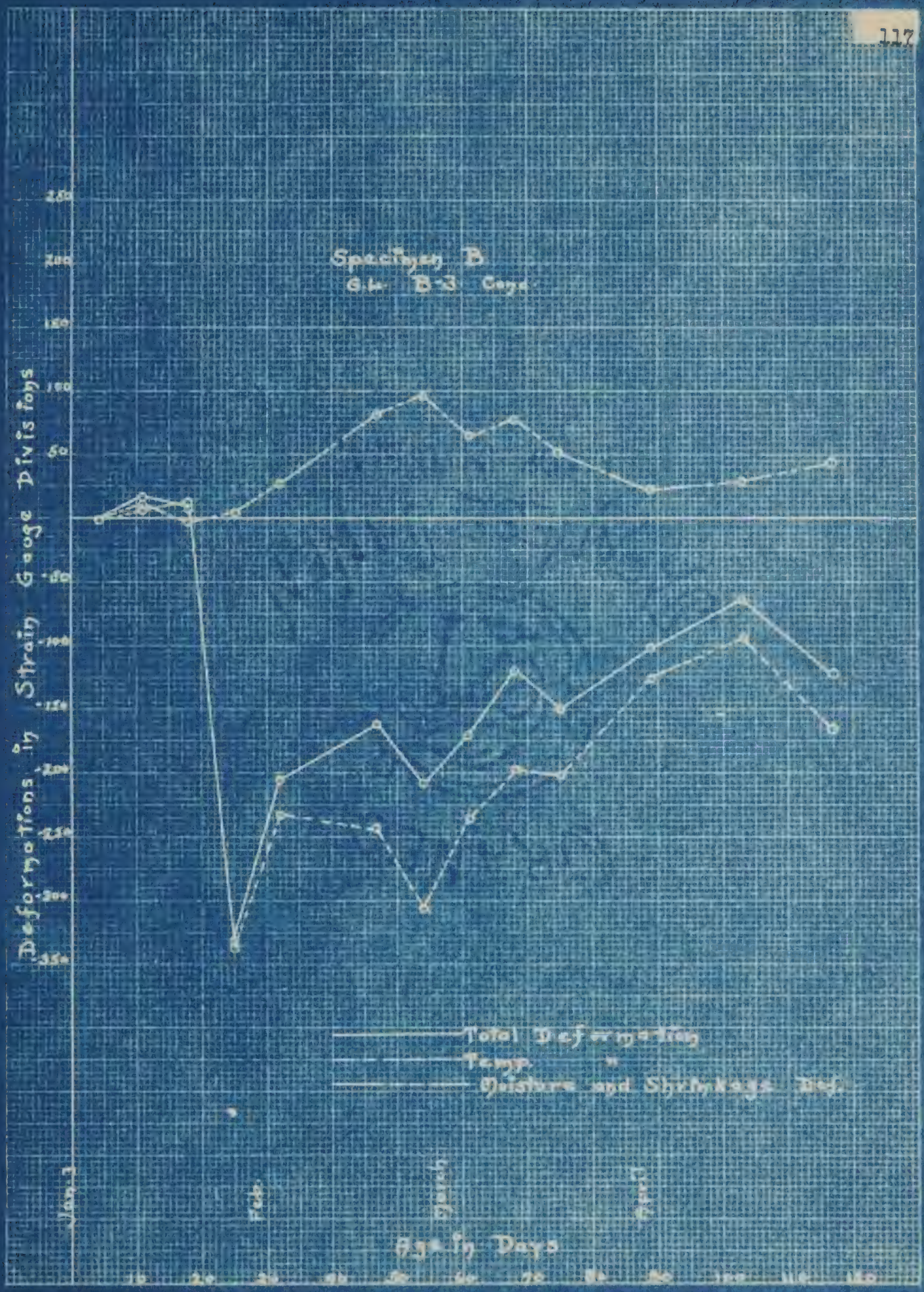

Specimen B
G.L. T-3 Conc.
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Age in Days

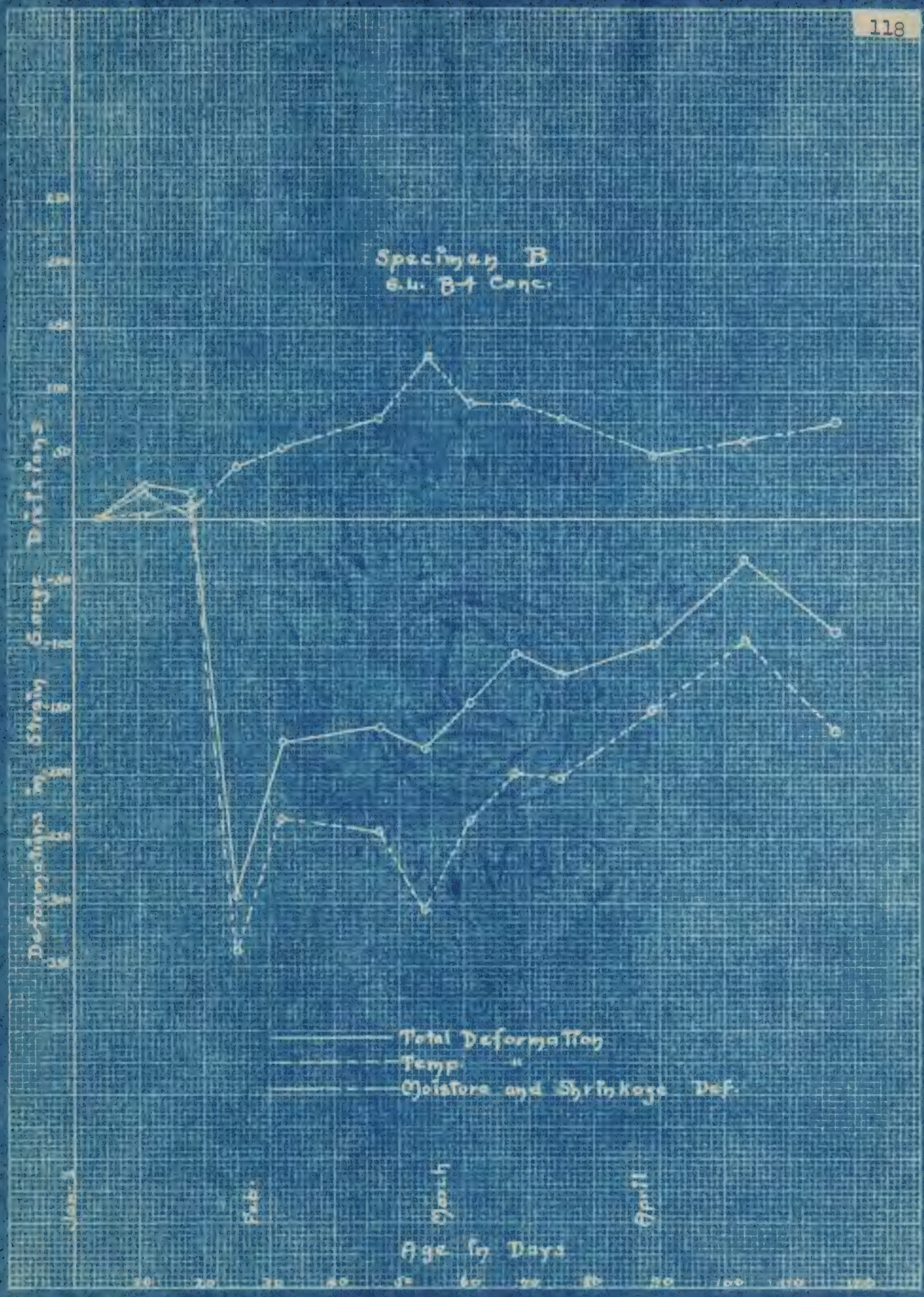

Specimen B
Total Deformation
Temp. "
Moisture and Shrinkage
Def.
Feb.
March
April
Age in Days


Specimen D
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days
Temp.
Strain Gauge Deformation

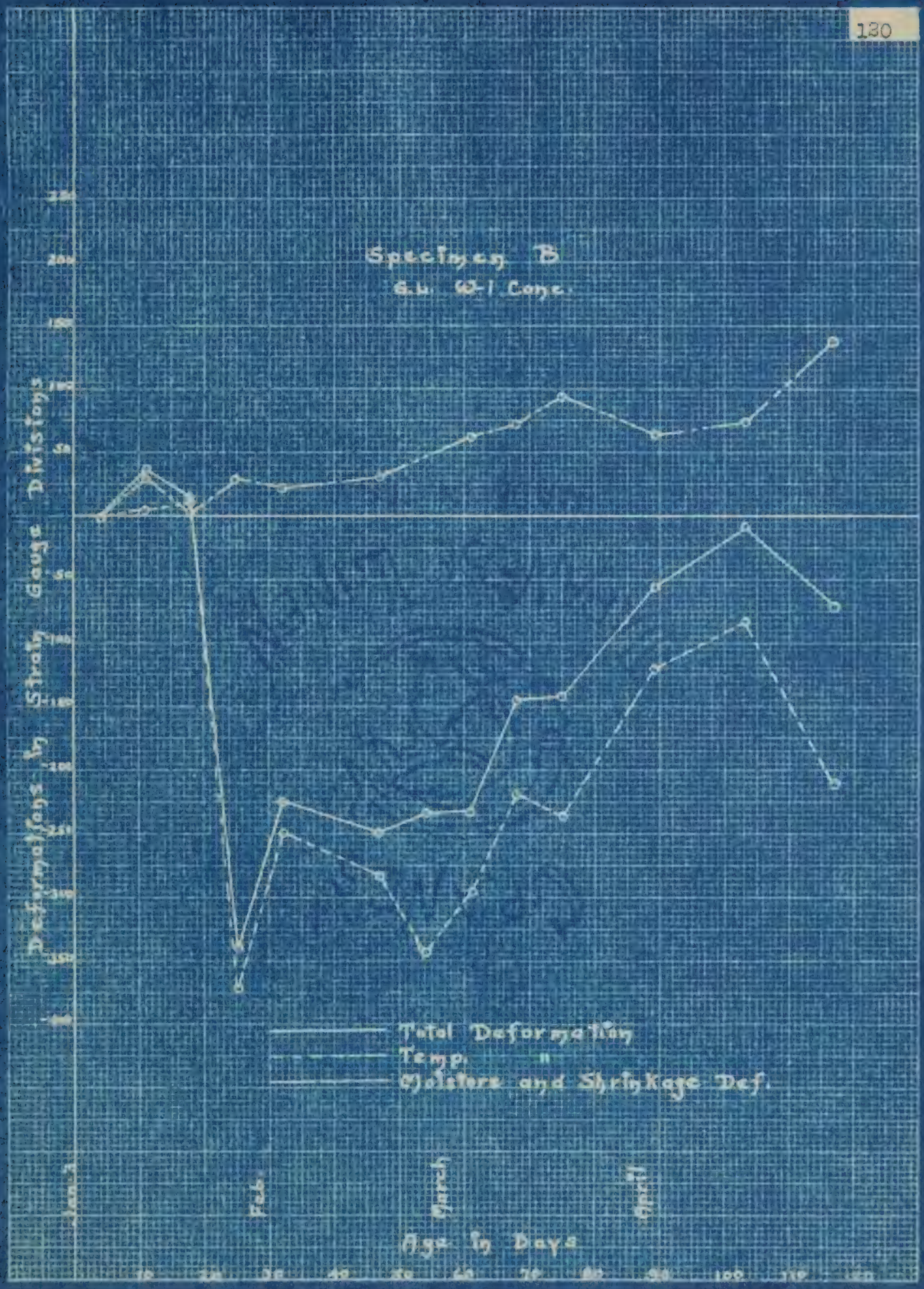

Specimen B
Gage B-1 Gage
Deformations in Strain Gauge Divisions
250
200
150
100
50
-50
-100
-150
-200
-250
-300
-350
Total Deformations
Temp. "
Moisture and Shrinkage Def.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

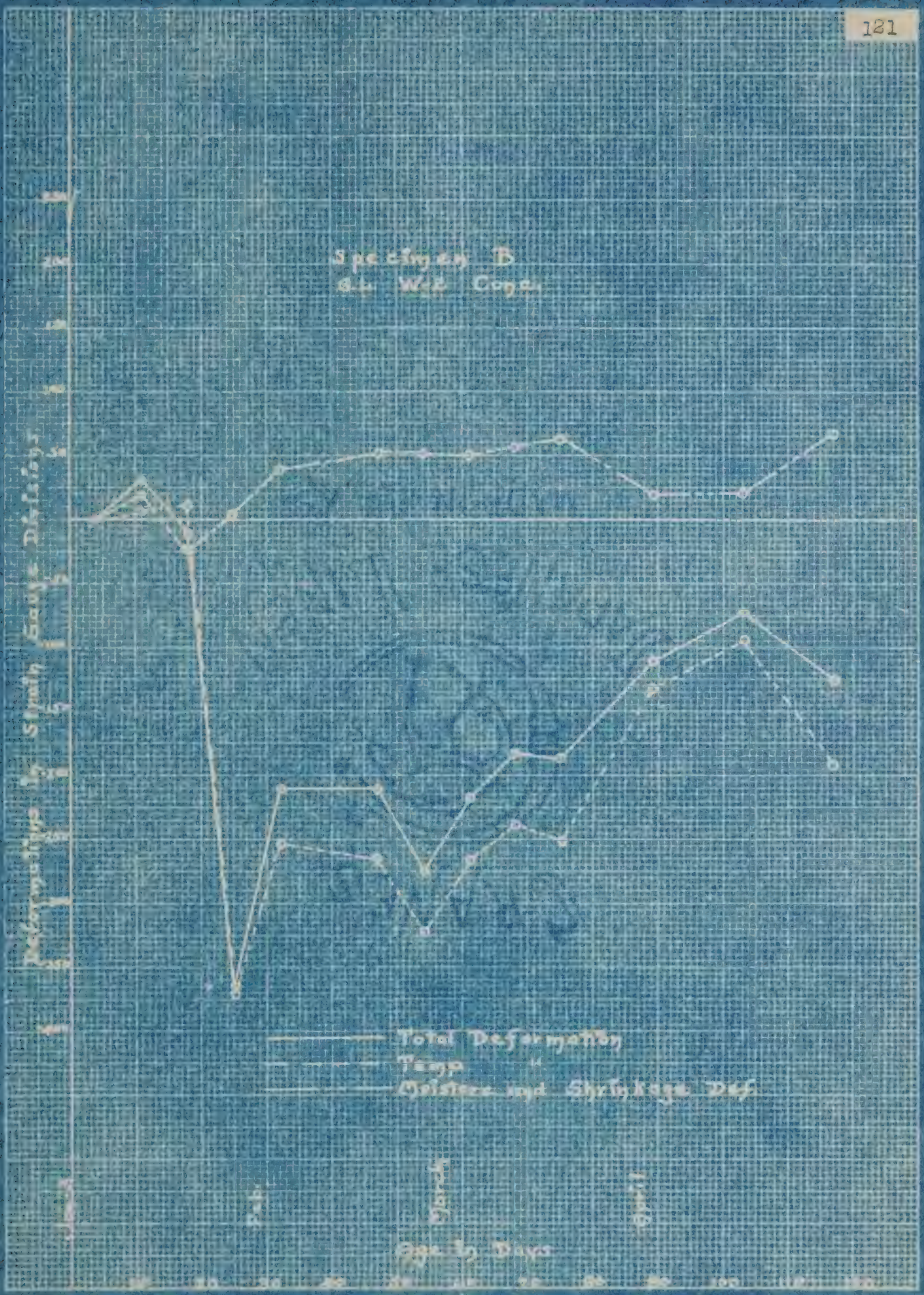
Specimen B
Gin. B-2 Conc
Deformations in Strain Gauge Divisions
Total Deformations
Temp. "
Moisture and Shrinkage Def.
Jan.
Feb.
March
April
Age in Days

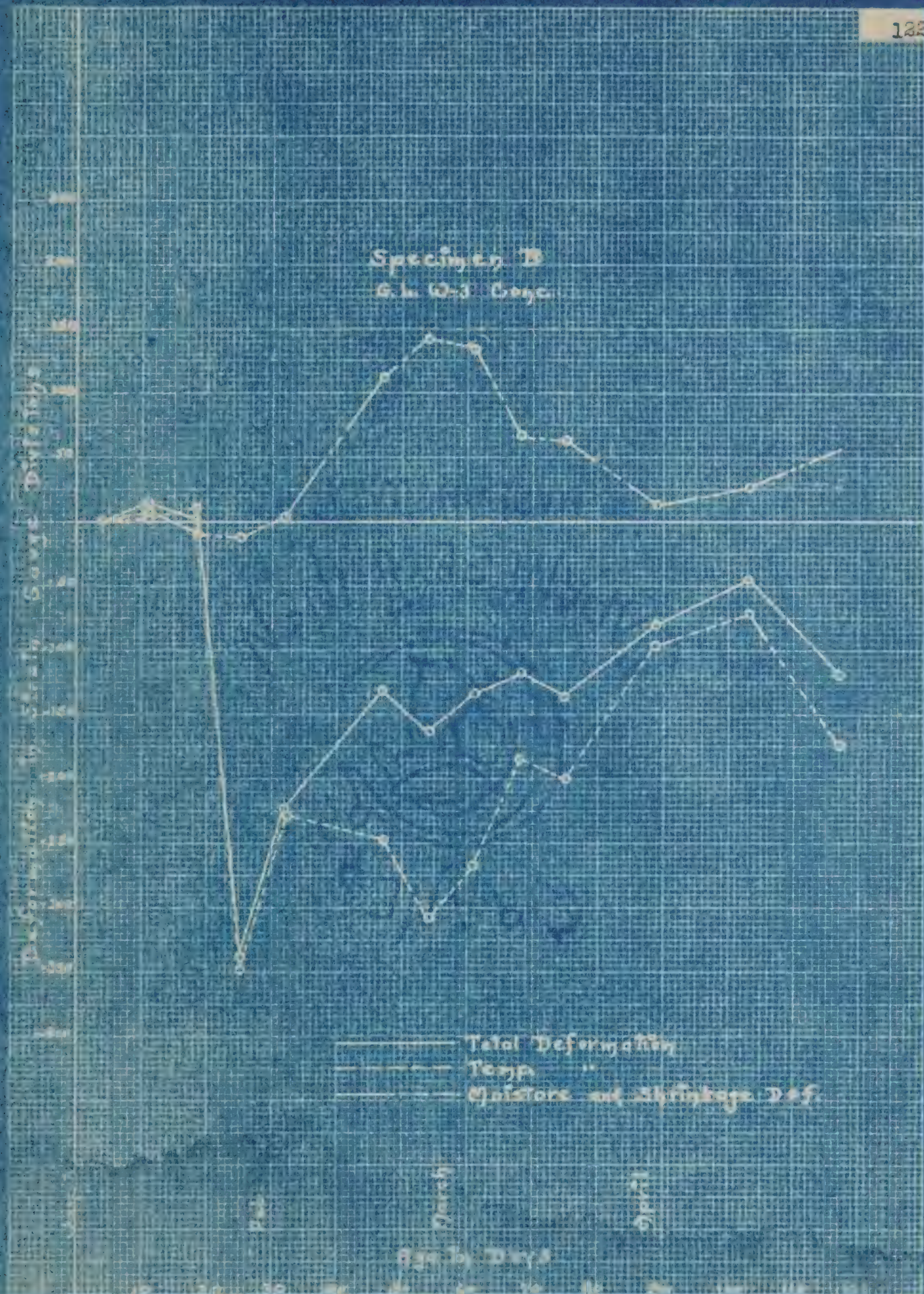

Specimen B
G.L. B-3 Cage
Deformations in Strain Gauge Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

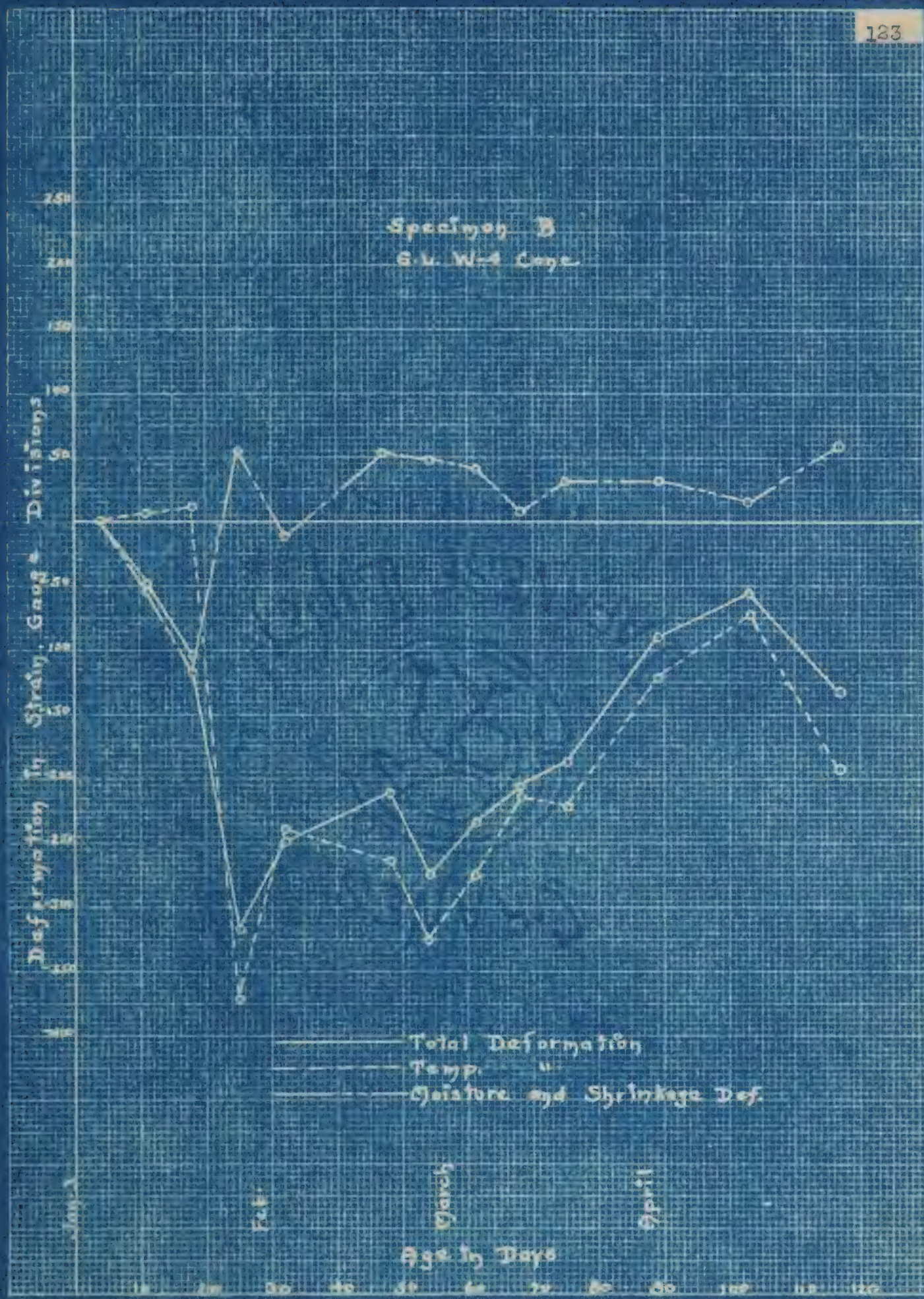

Specimen B
6.4. B-1 Conc.
Deformations in Strain Gauge Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

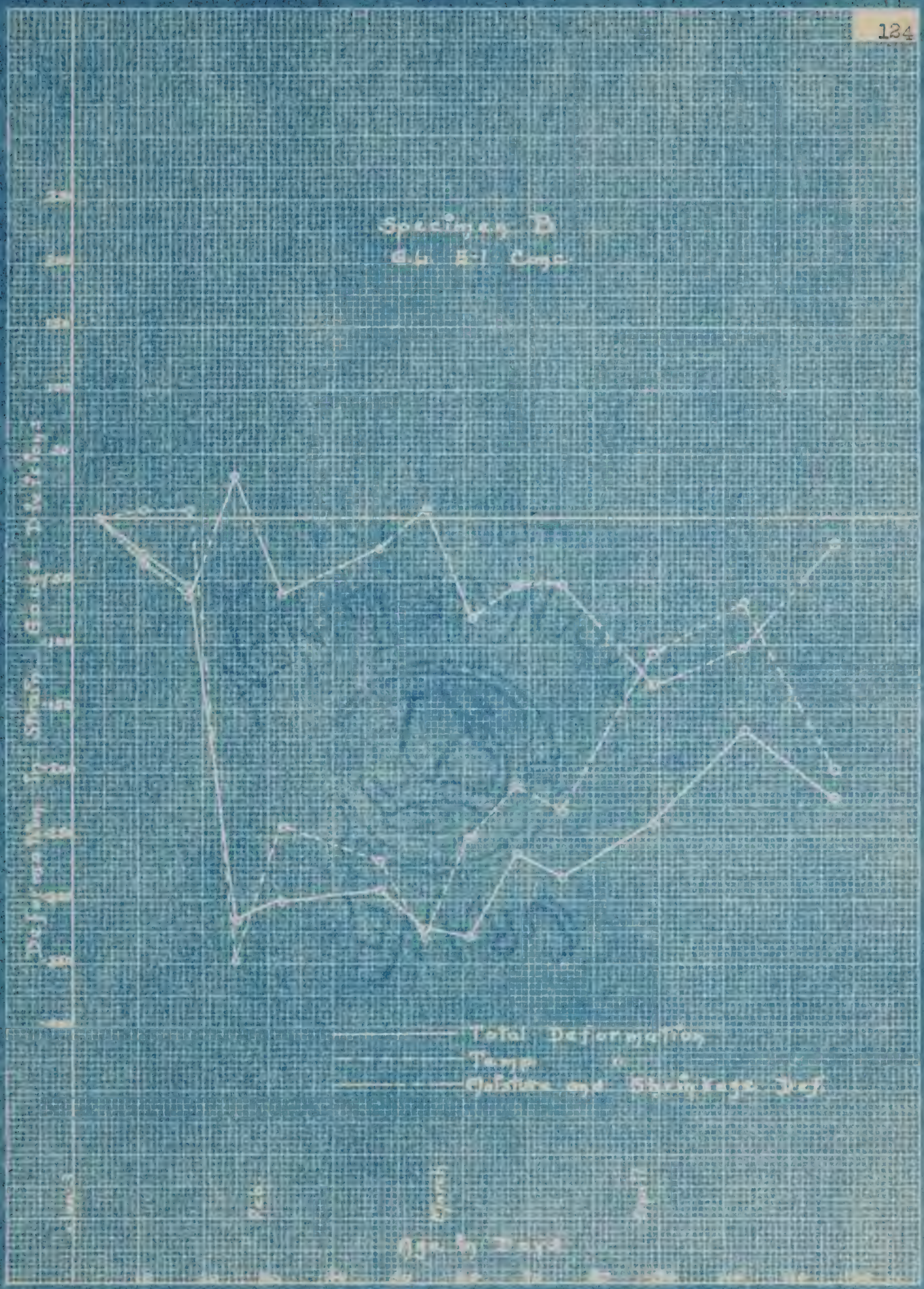
Specimen D
S.L. B-½ Gage
Deformations by Steady Gage Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

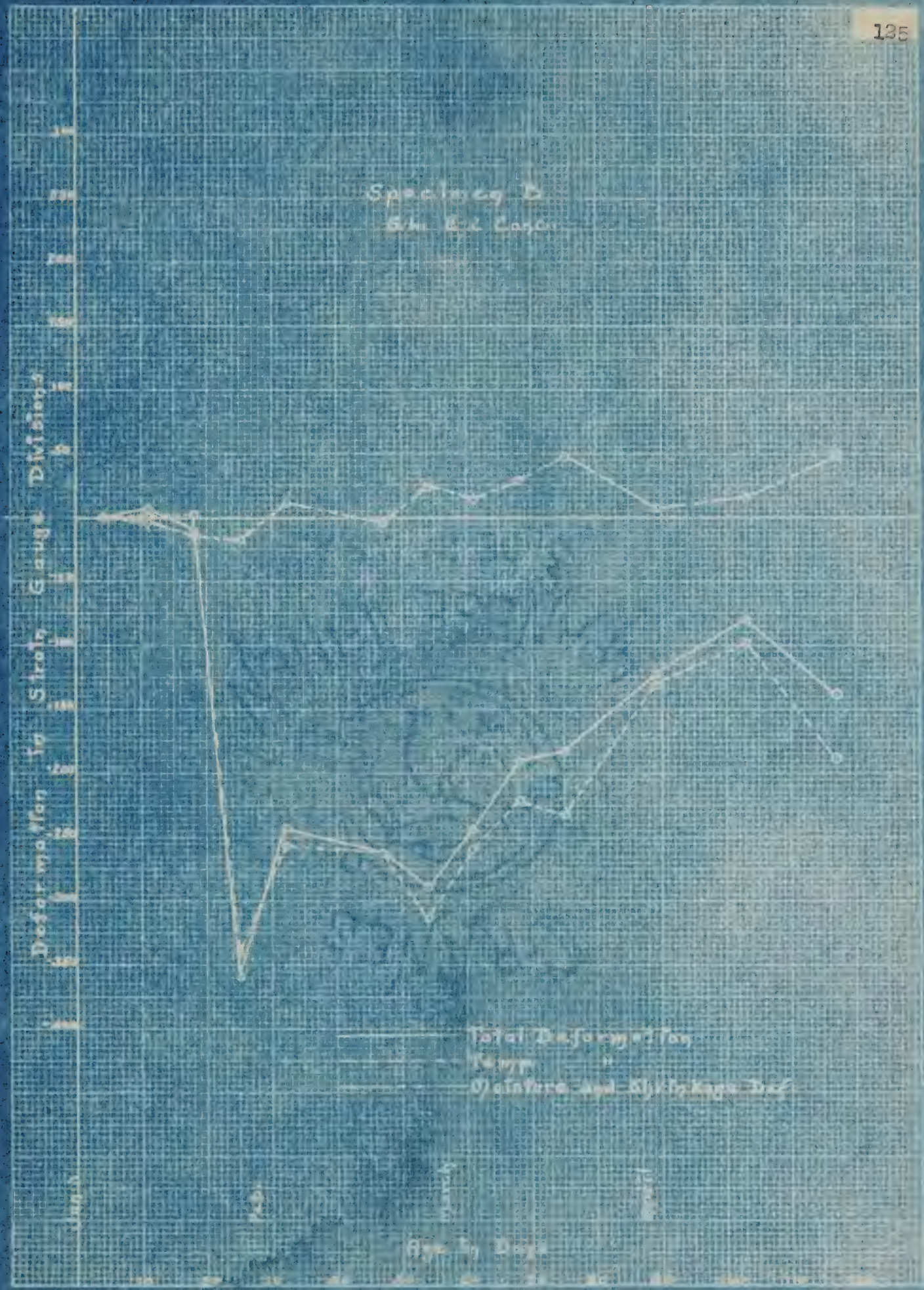

Specimen B
S.U. W-1 Conc.
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Deformations by Strain Gauge Divisions
Age in Days
Feb.
March
April

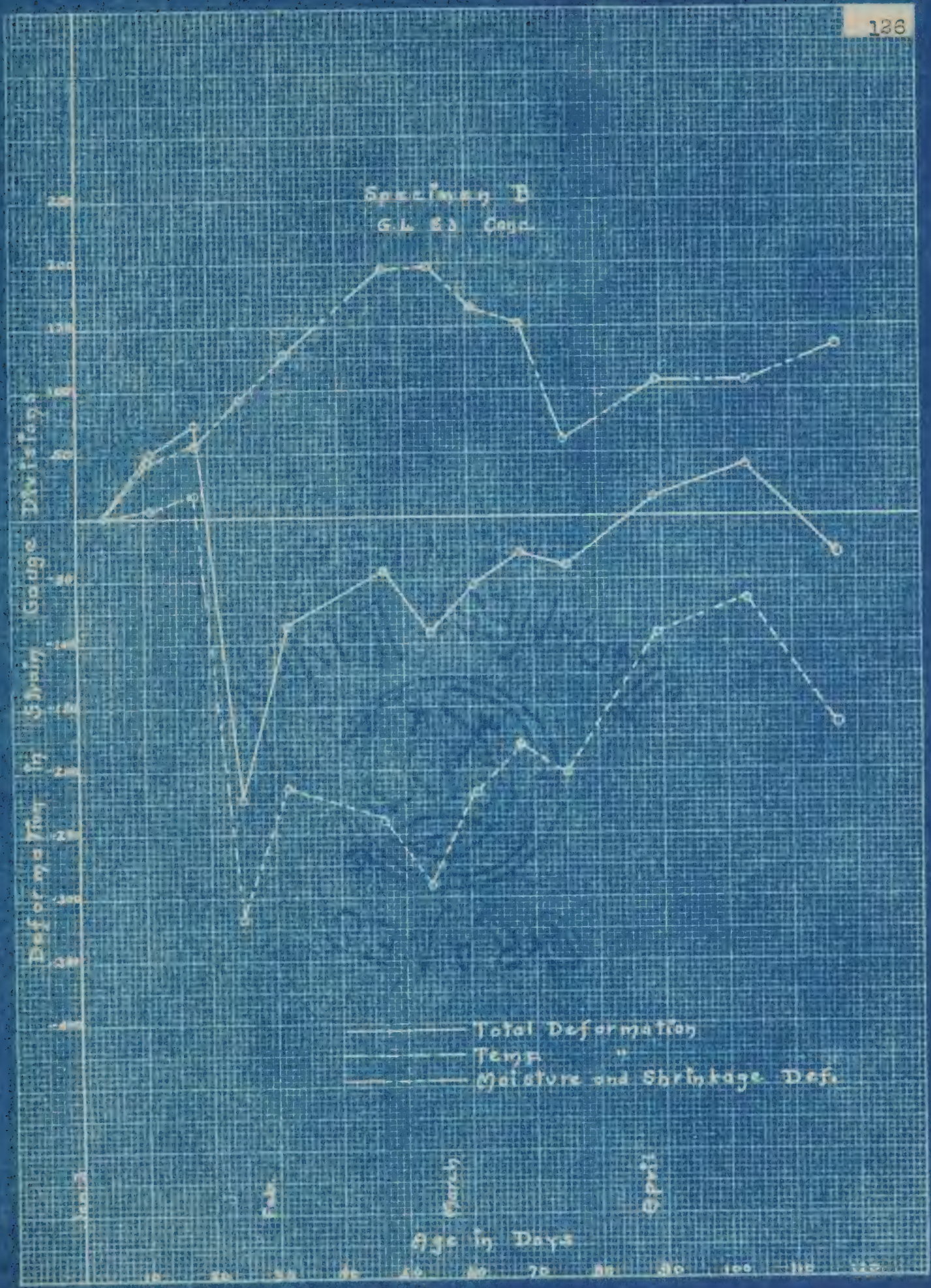

Specimen D
Total Deformation
Temp
Creep and Shrinkage Def
Age in Days

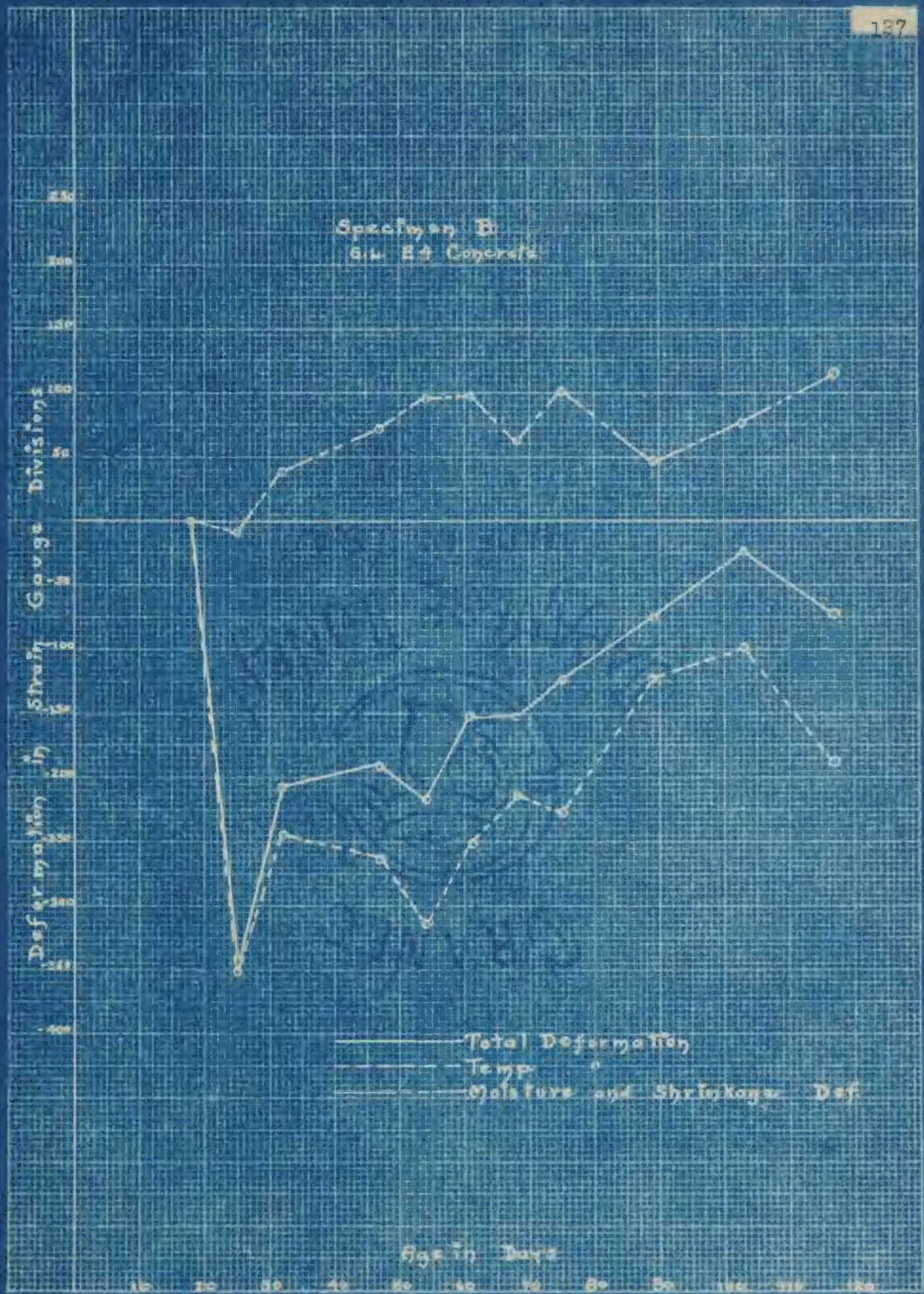

Specimen B
Total Deformation
Temp. "
Uniform and Hydrogen Def.

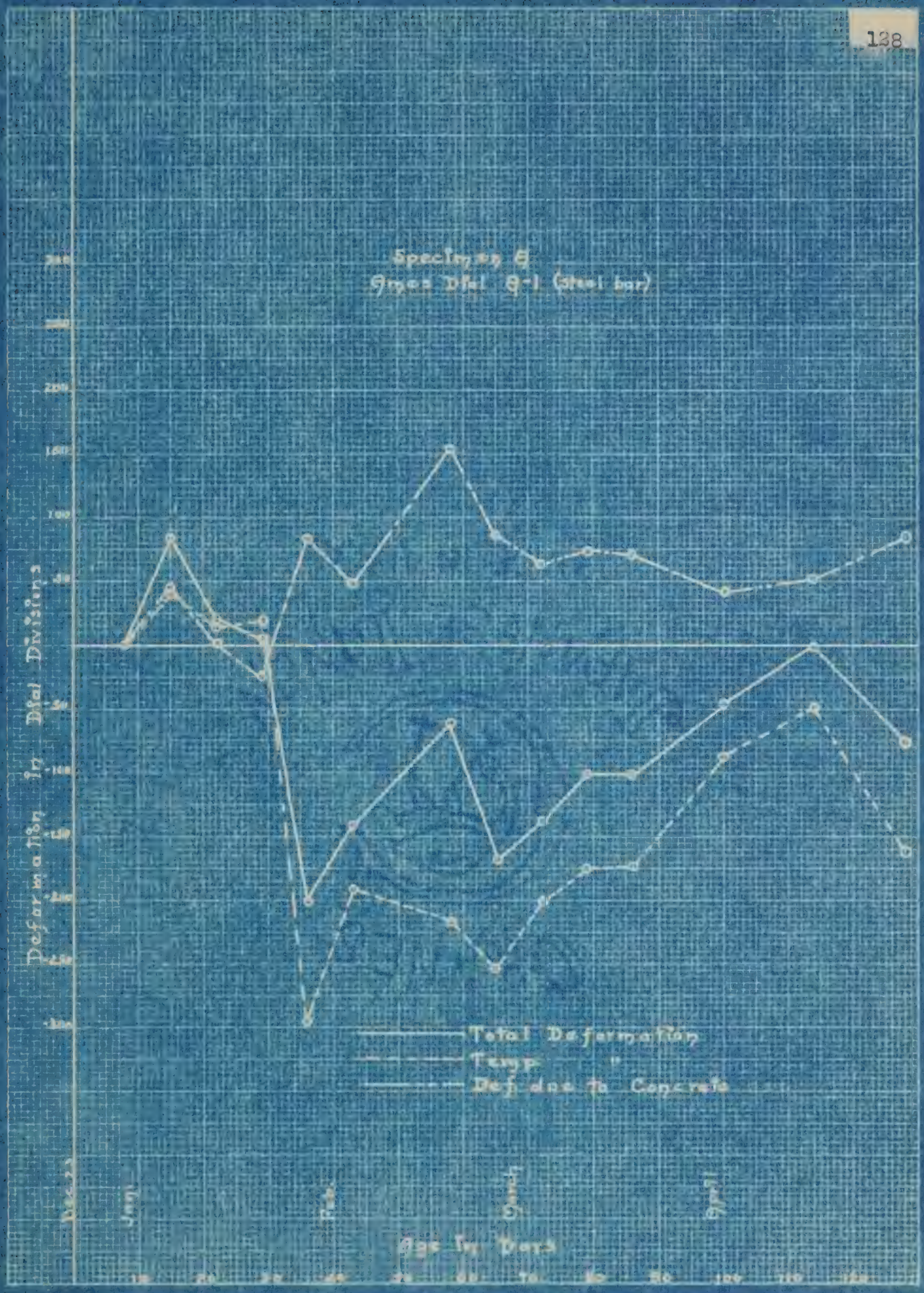

Specimen B
G.L. W-4 Gage
Deformation in Strain Gage Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

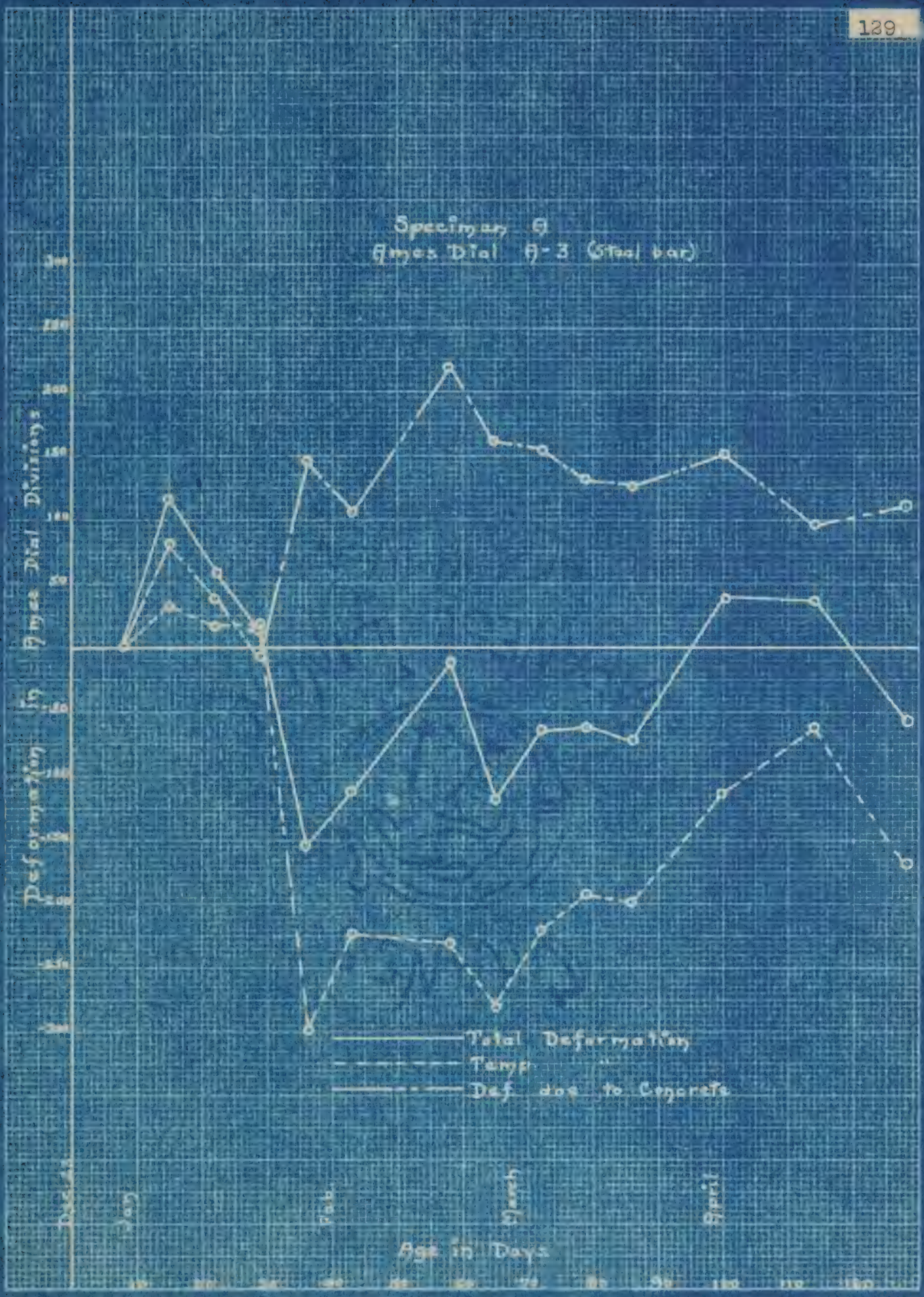

Spaulding's B
Total Deformation
Theory
Observed Spaulding's Data

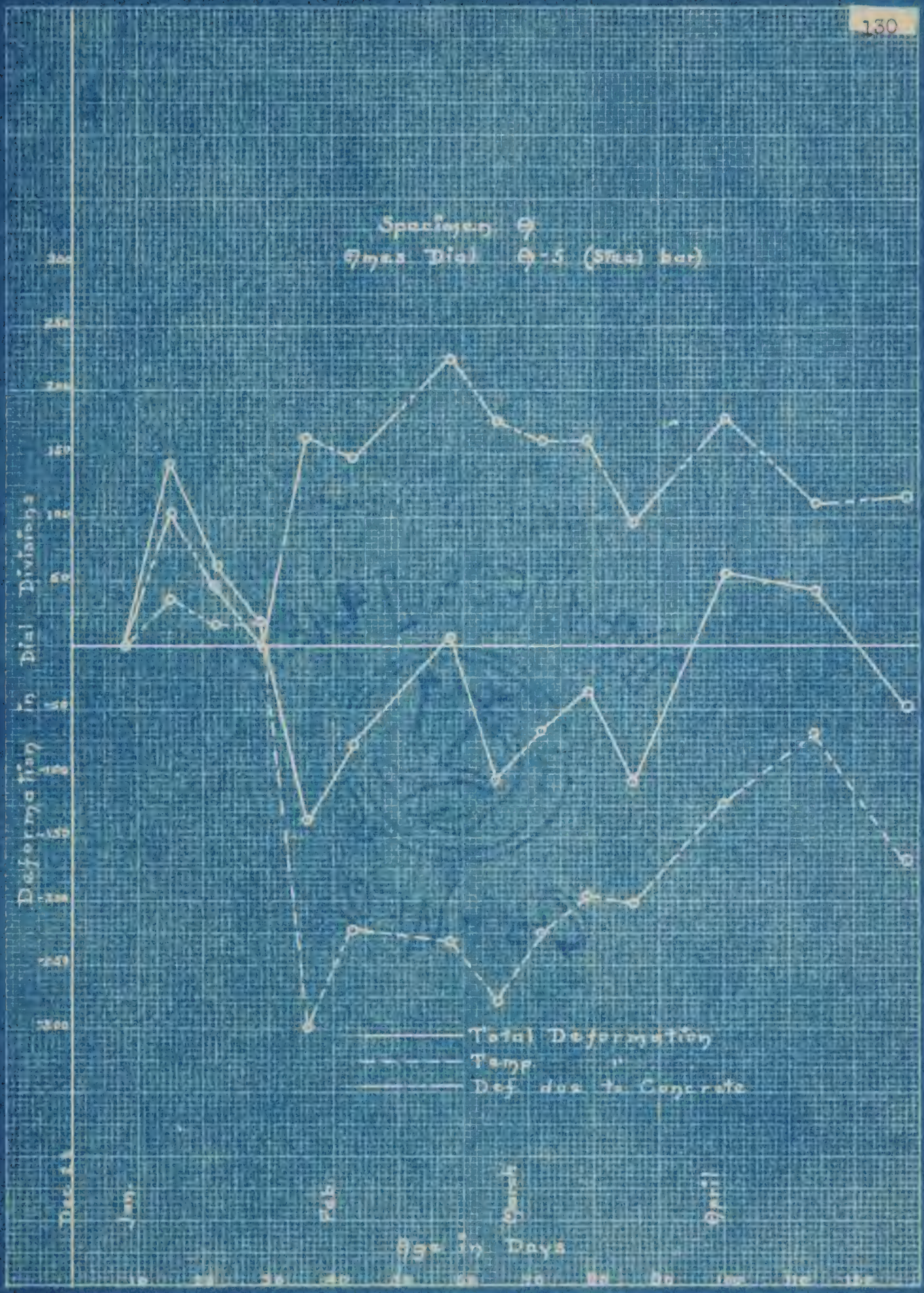

Specimen B
Deformation in Sixth Gauge Divisions
Total Deformation
Warpage and Shrinkage Def.
Arch in Days

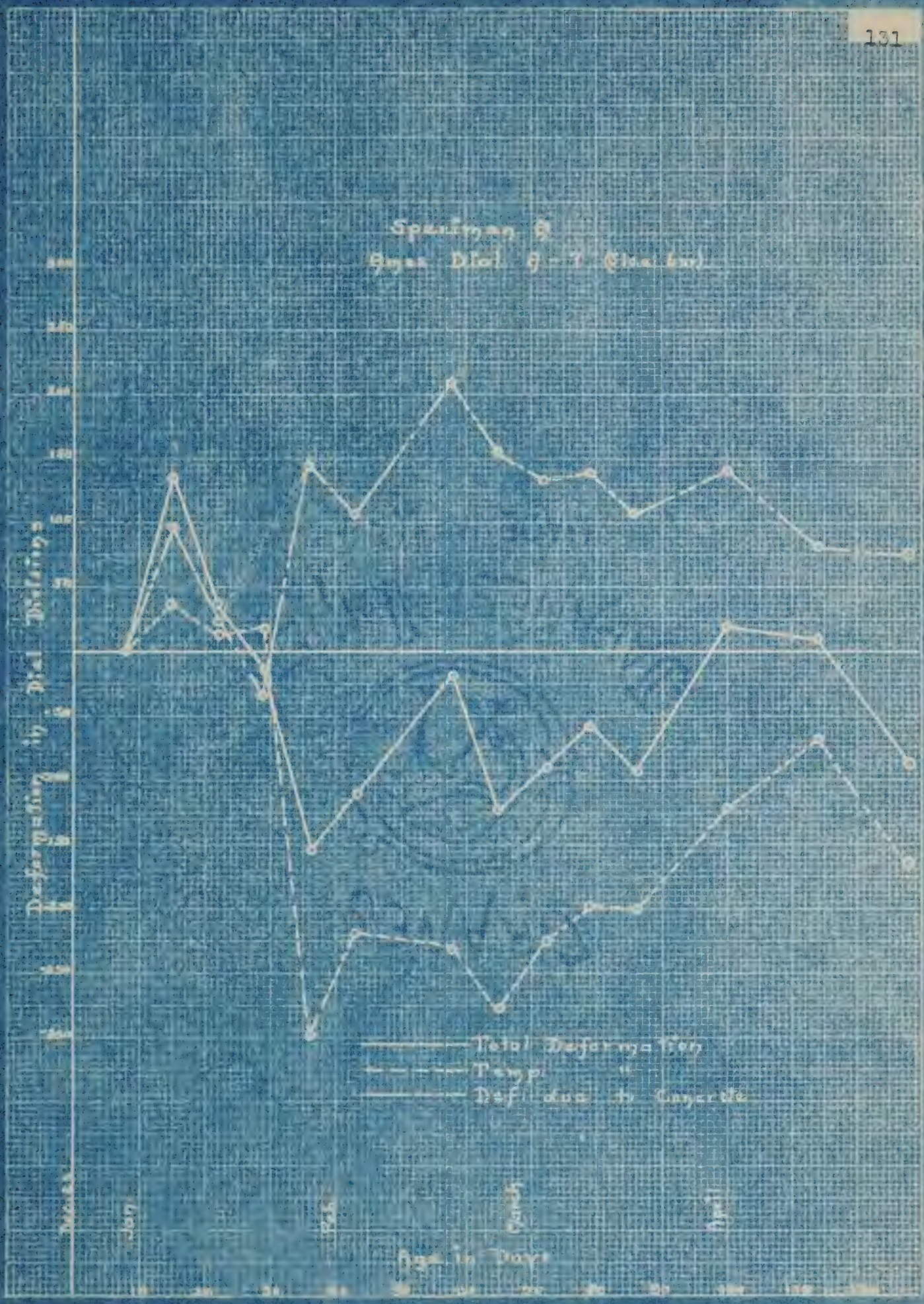

Specimen B
G.L. 23 Gage
Deformation in Unit Gauge Divisions
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Age in Days

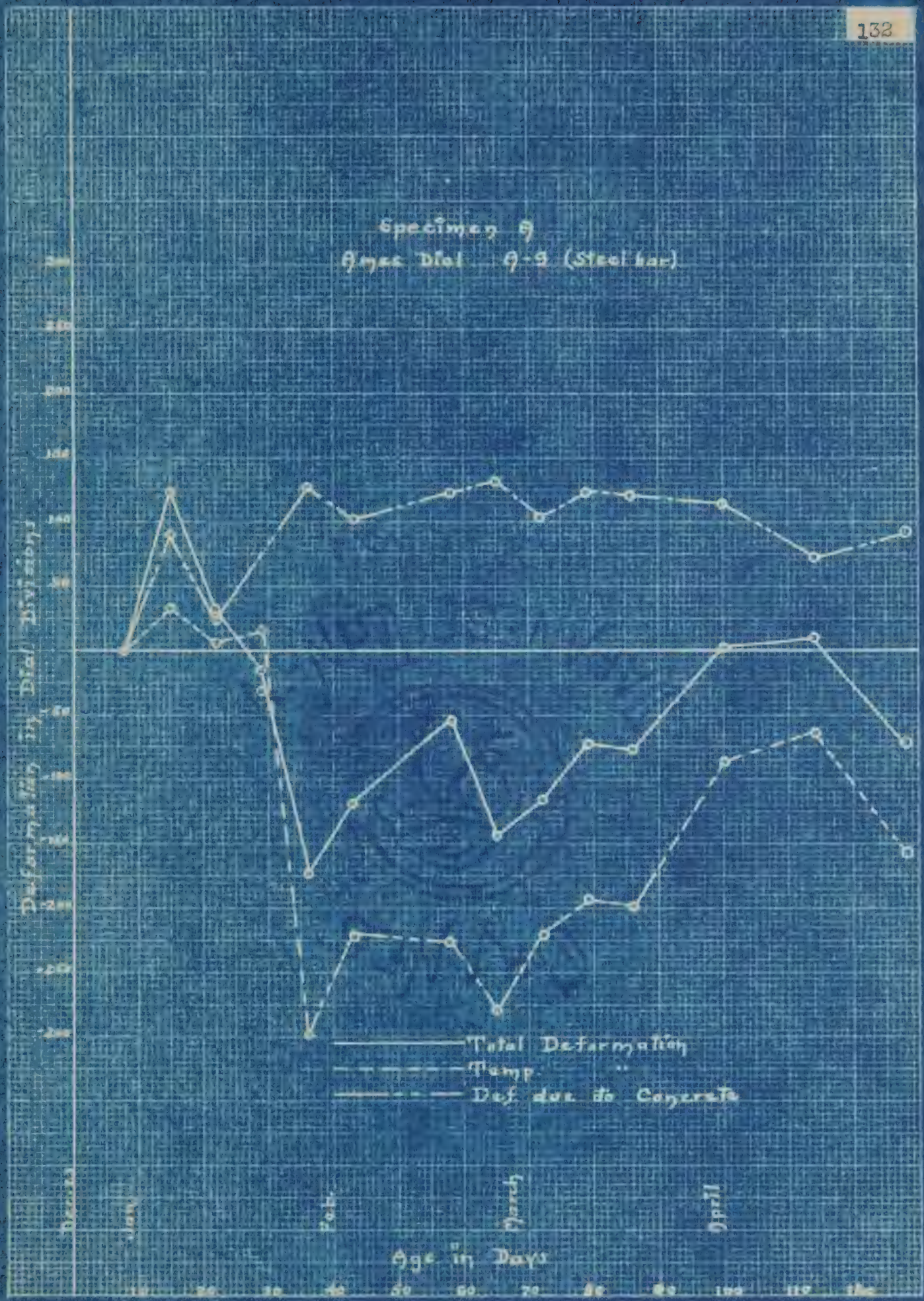

Specimen B
G.W. E.4 Concrete
Deformation in Strain Gauge Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def.
Age in Days

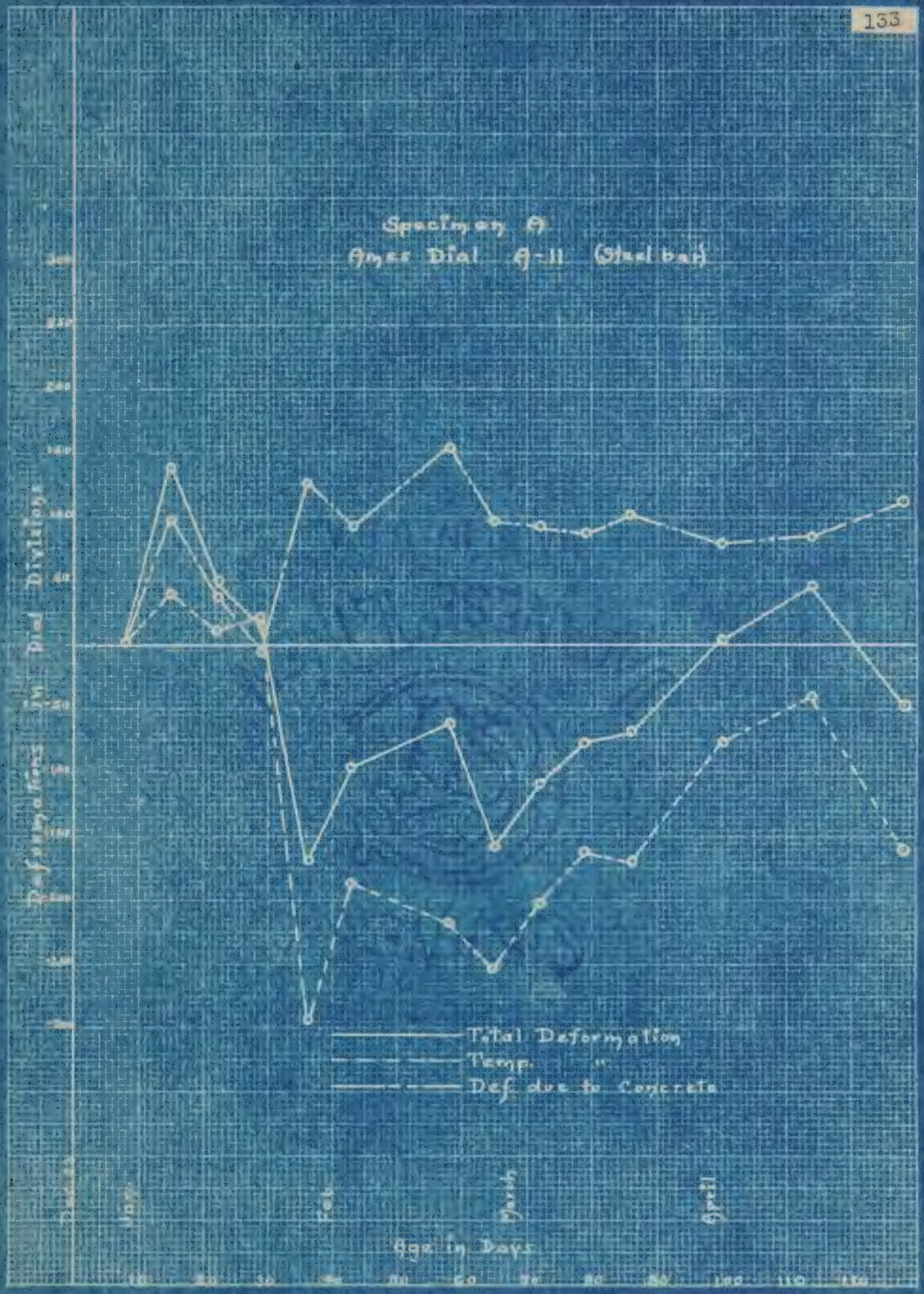

Specimen 6
Gages Dial 8-1 (steel bar)
Deformation in Dial Divisions
Total Deformation
Temp. "
Def due to Concrete
Age in Days

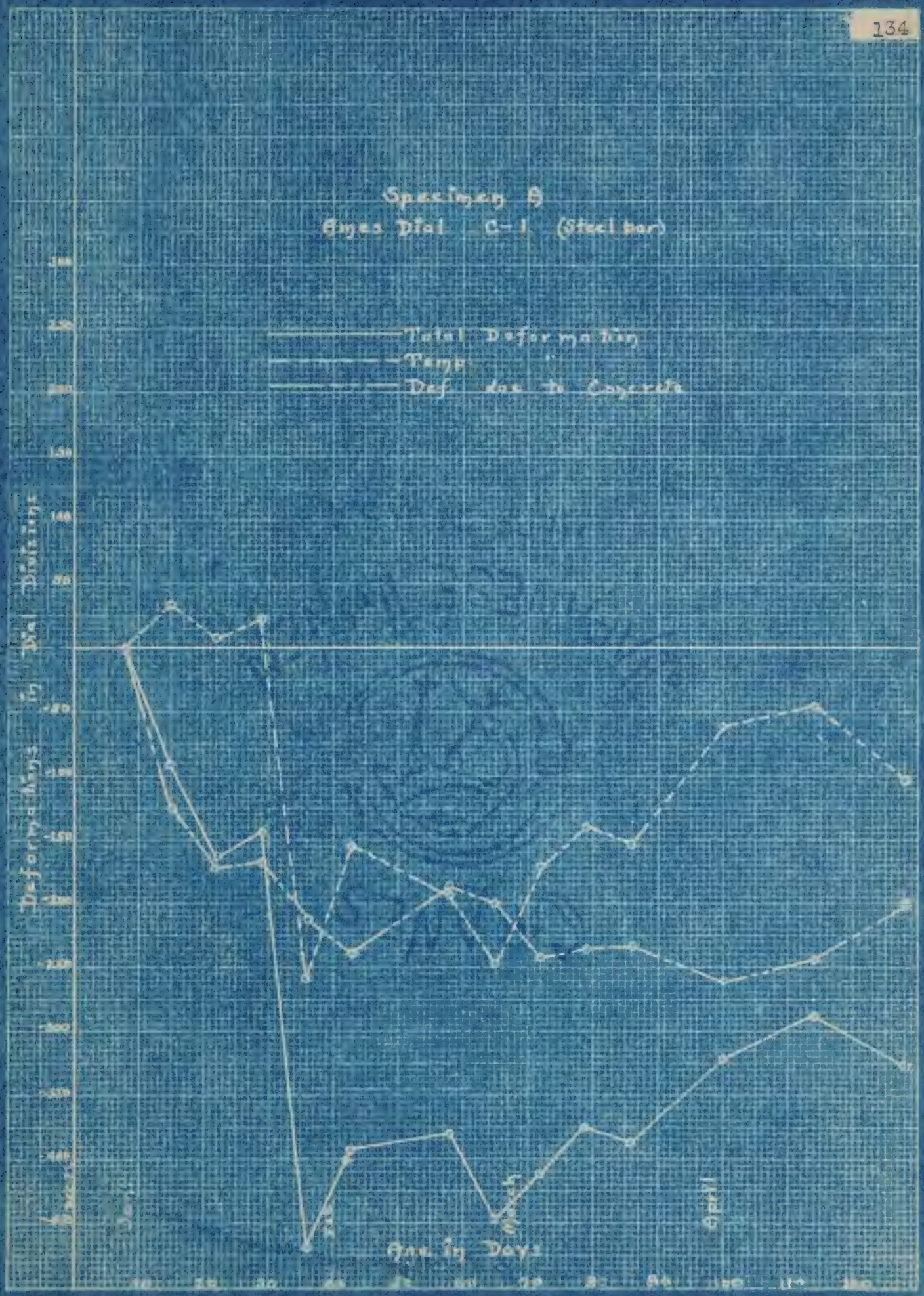

Specimen G
Ames Dial A-3 (Steel bar)
Deformation in Ames Dial Divisions
Total Deformation
Temp
Def due to Concrete
Jan
Feb
March
April
Age in Days

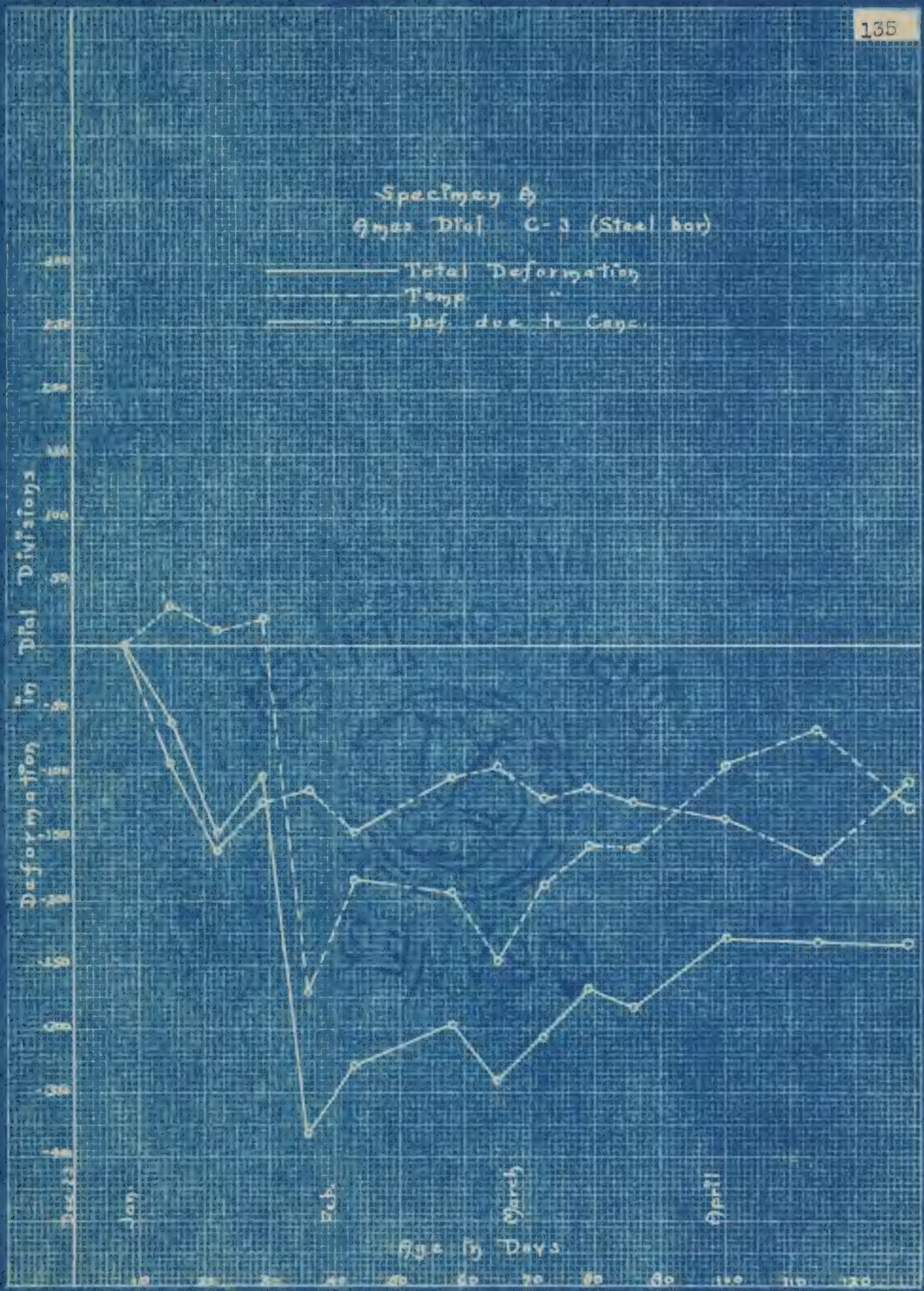

Specimen 9
9mm Dial 9-5 (Steel bar)
Deformation in Dial Divisions
Total Deformation
Temp "
Def due to Concrete
Jan
Feb
March
April
Age in Days

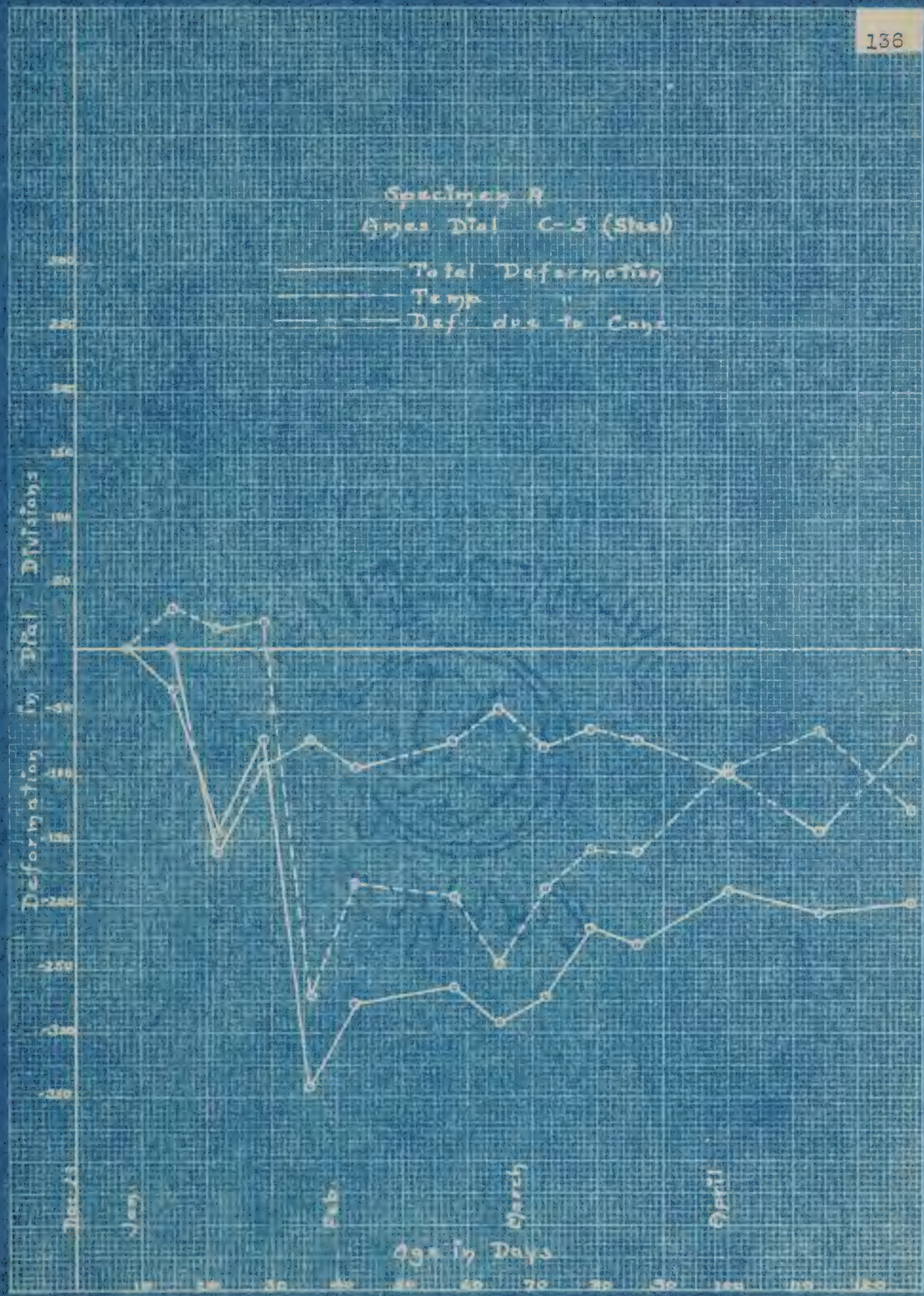

Specimen 9
Total Deformation
Temp
Def due to Unyield
Age in Days

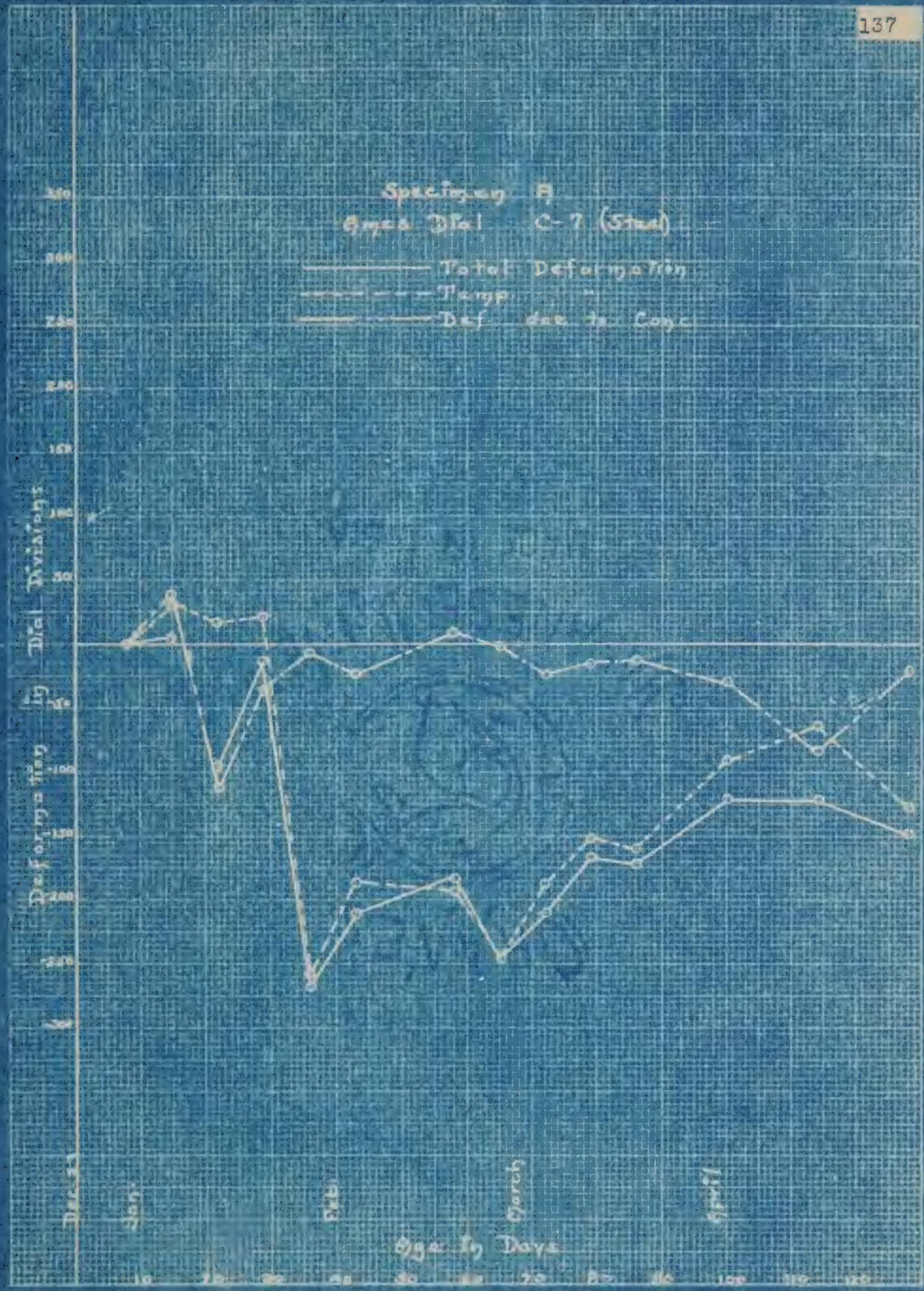

Specimen 9
9 Mec Dial 9-9 (Steel bar)
Total Deformation
Temp
Def due to Concrete
Deformation in Dial Divisions
Age in Days
Jan
Feb
March
April

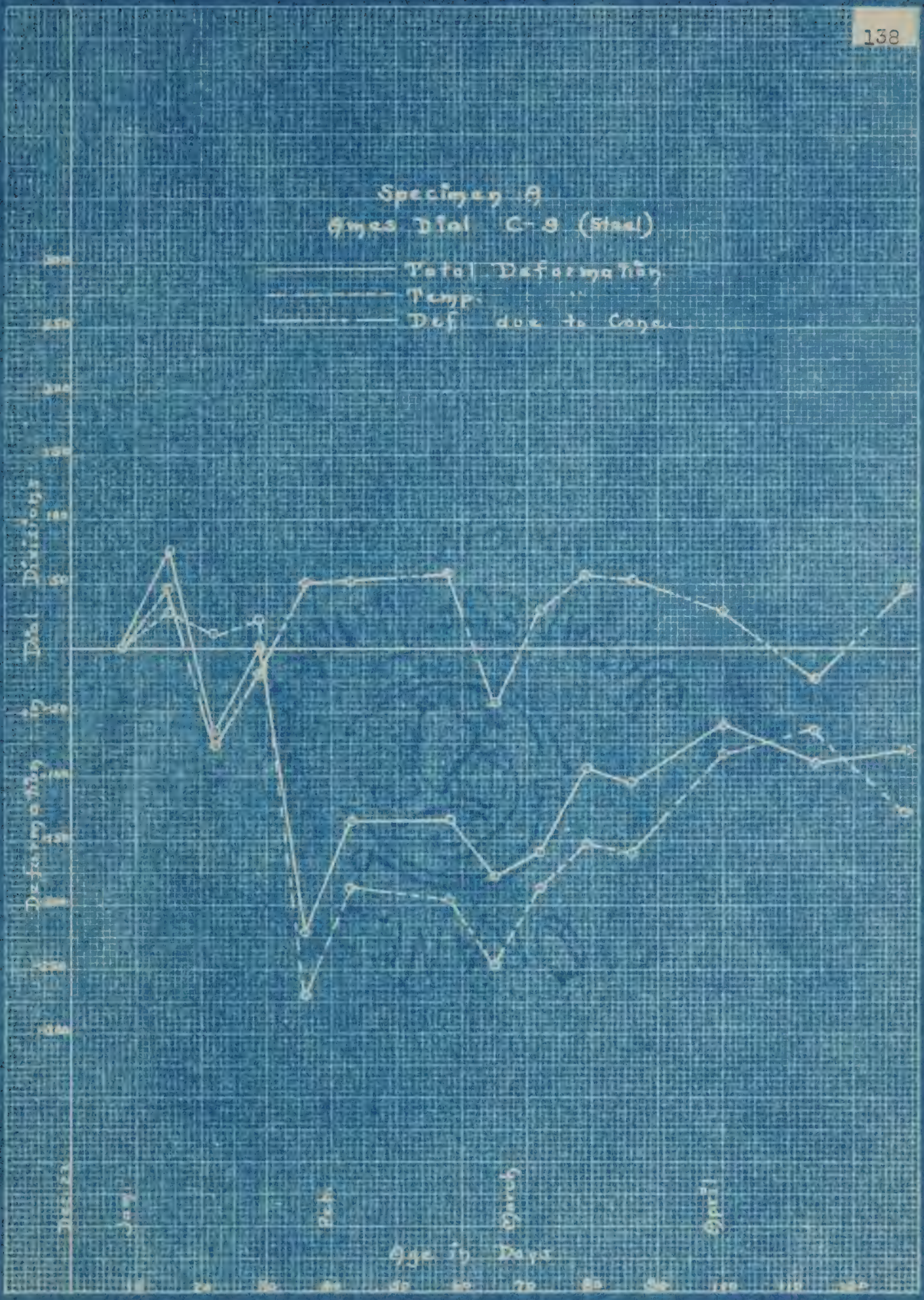

Specimen A
Ames Dial A-11 (Steel bar)
Deformations in Dial Divisions
Total Deformation
Temp. "
Def. due to Concrete
Jan.
Feb.
March
April
Age in Days

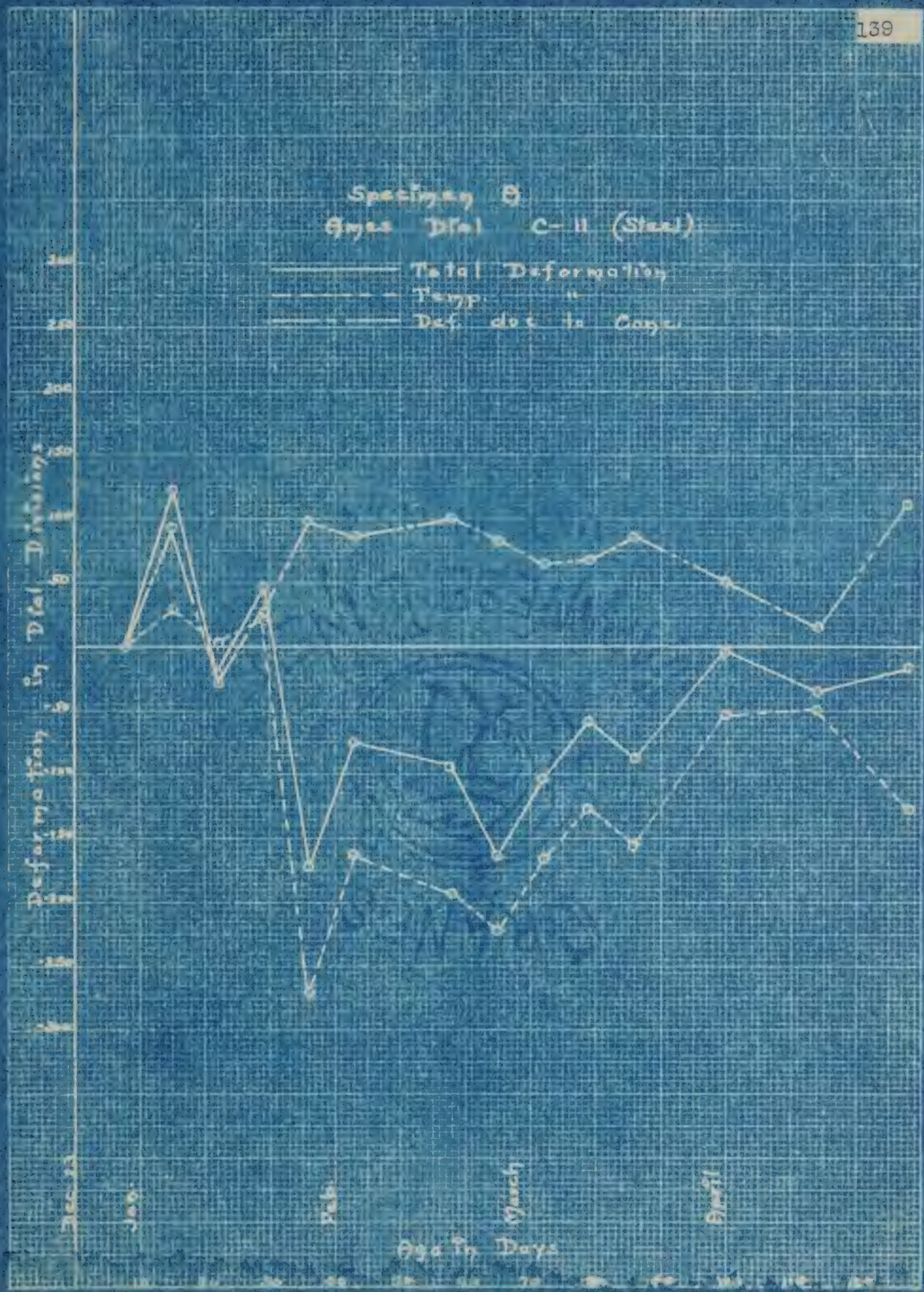

Specimen B
Ames Dial C-1 (Steel bar)
Total Deformation
Temp
Def due to Concrete
Deformations (in) Dial Distance
Age in Days
April

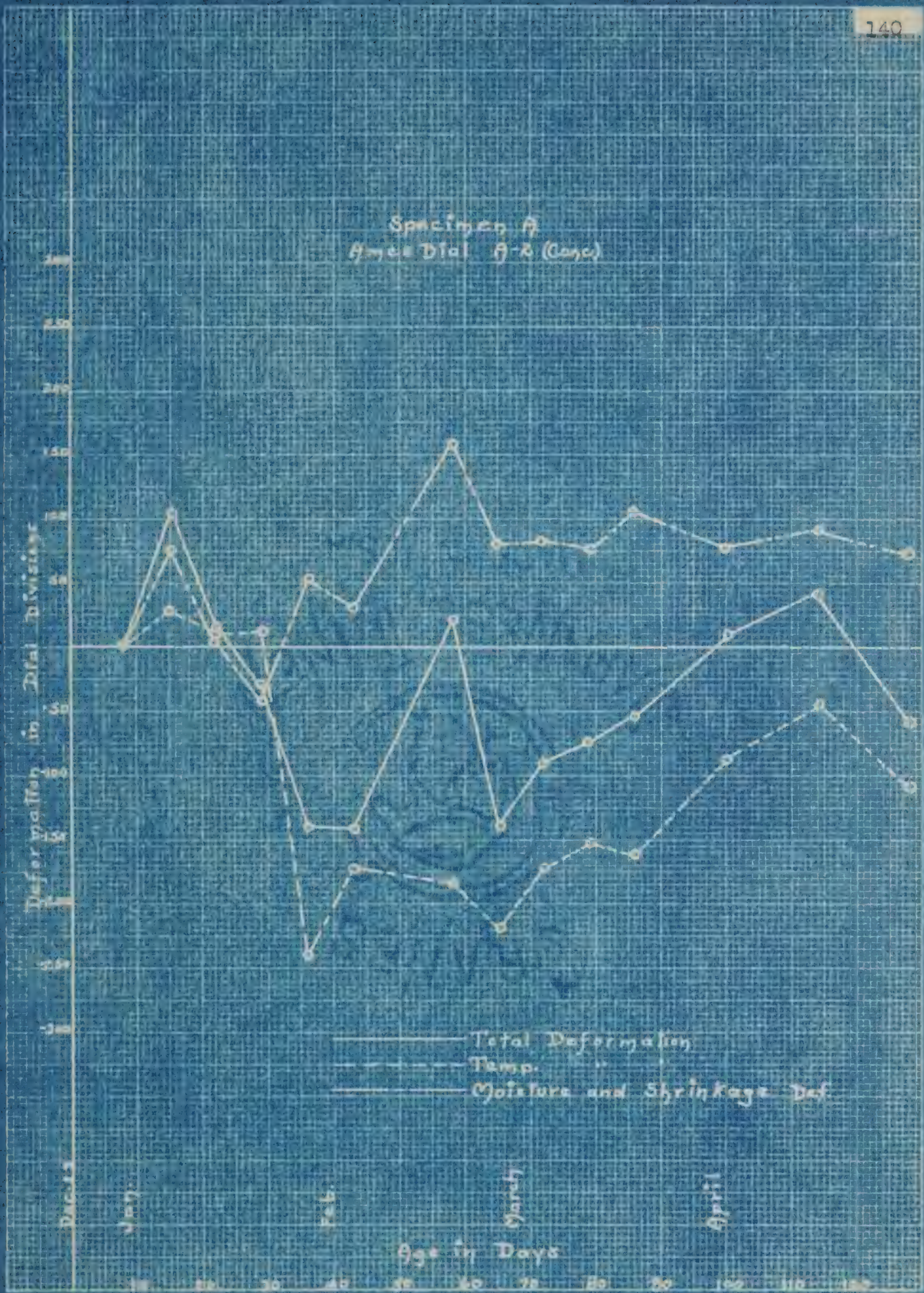

Specimen A
Ames Dial C-3 (Steel bar)
Total Deformation
Temp.
Def. due to Cage
Deformation in Dial Divisions
Jan.
Feb.
March
April
Age in Days

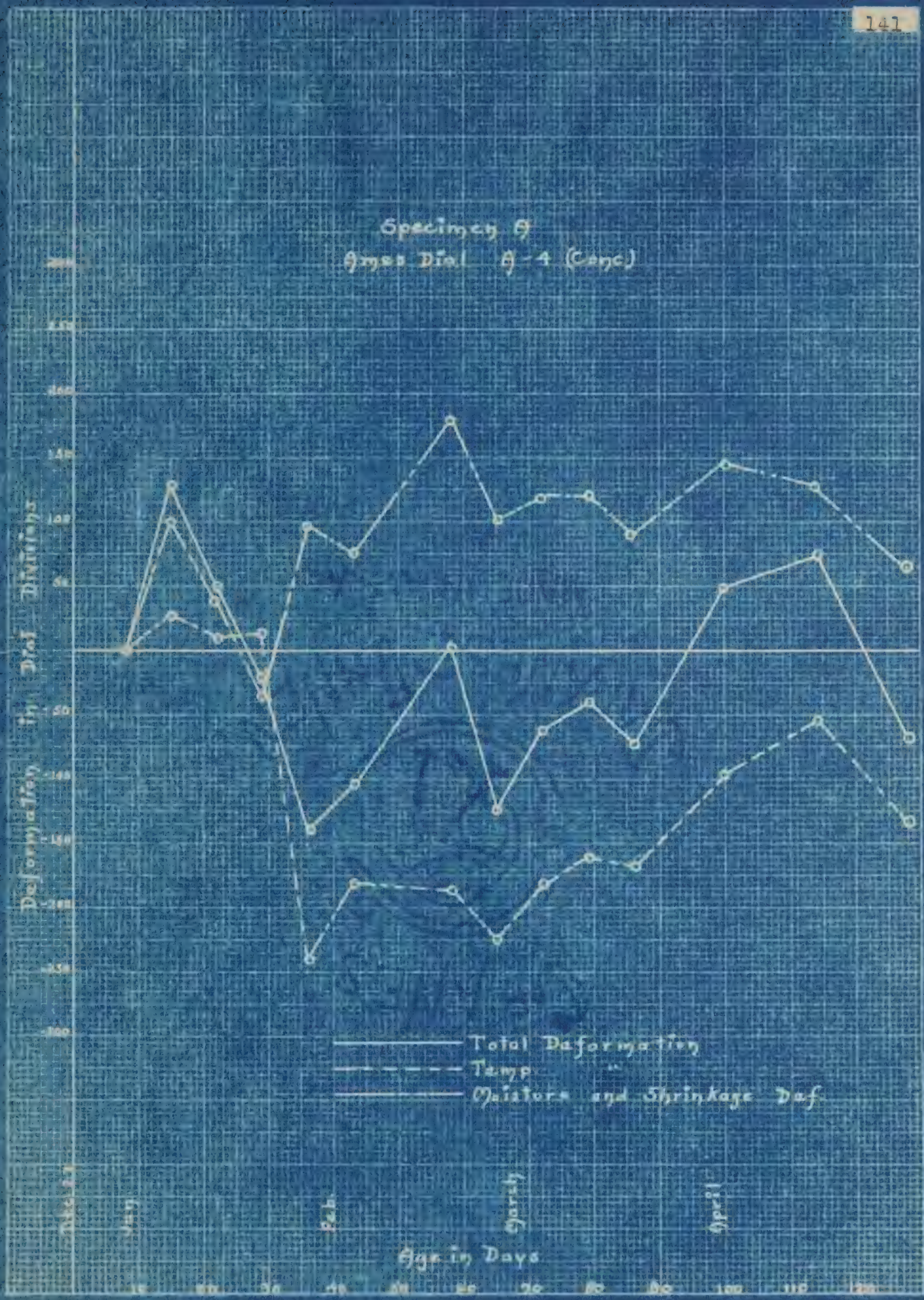

Specimen A
Ames Dial C-5 (Steel)
Total Deformation
Temp.
Def. due to Creep
Deformation by Dial Divisions
Age in Days
Jan.
Feb.
March
April


Specimen H
Gage Dial C-7 (Steel)
Total Deformation
Temp
Def due to Comp
Deformation by Dial Divisions
Dec 31
Jan
Feb
March
April
Age in Days

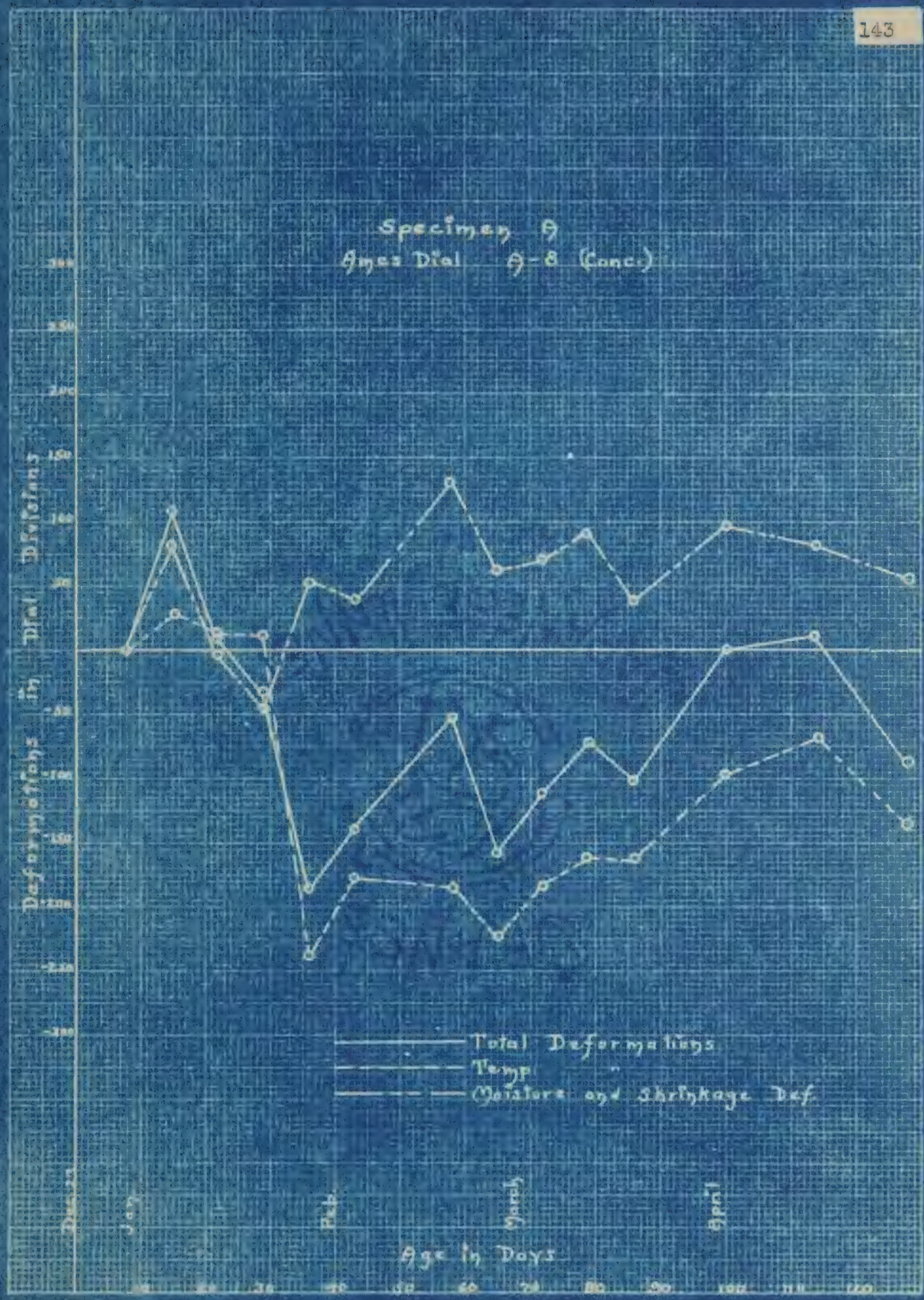

Specimen A
Gages Dial C-9 (Steel)
Total Deformation
Temp.
Def. due to Conc.
Dial Divisions
Deformation
Age in Days

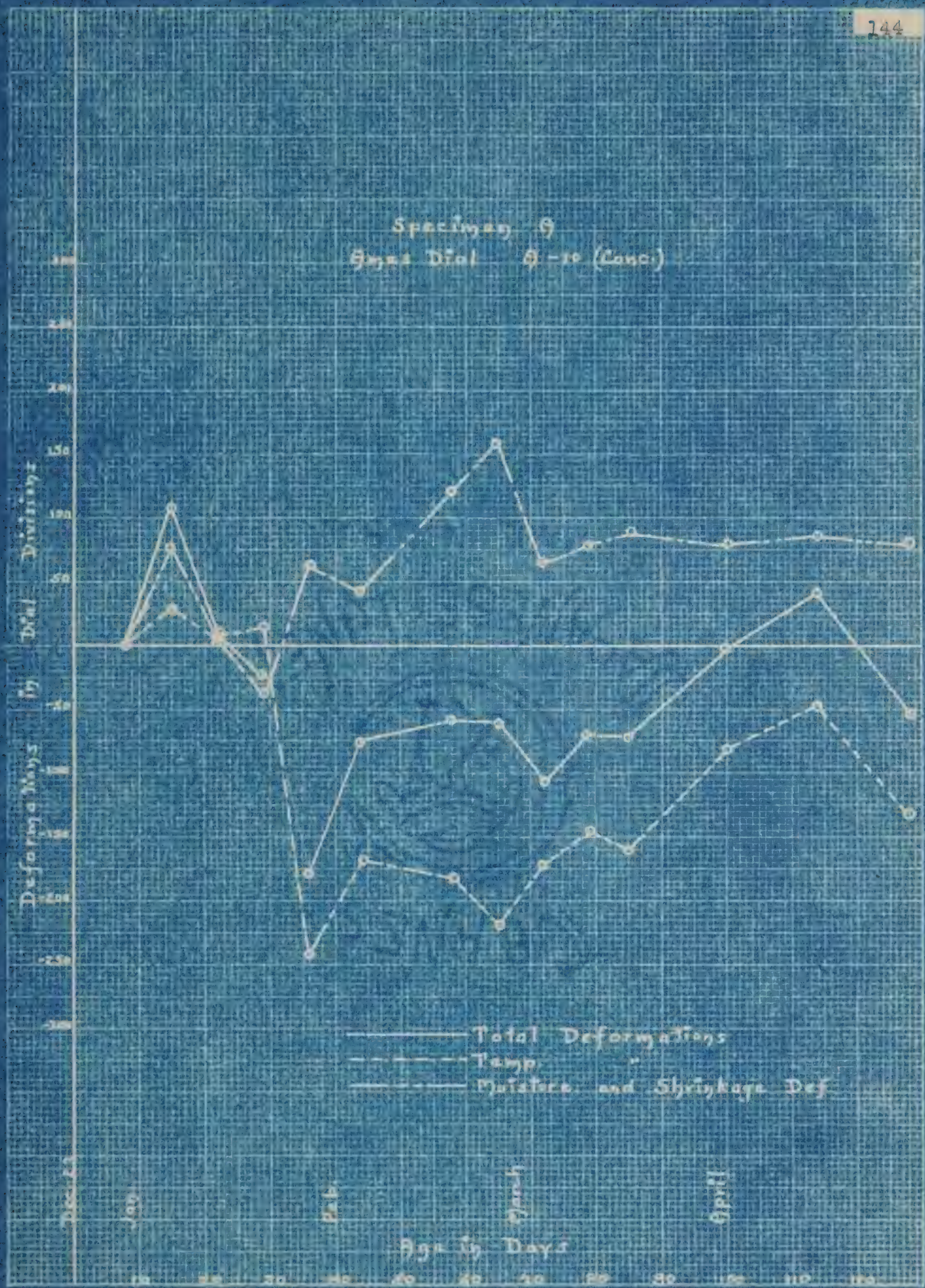

Specimen 8
Ames Dial C-11 (Steel)
Total Deformation
Temp. "
Def. due to Gage
Deformation in Dial Divisions
Dec.
Jan.
Feb.
March
April
Age in Days

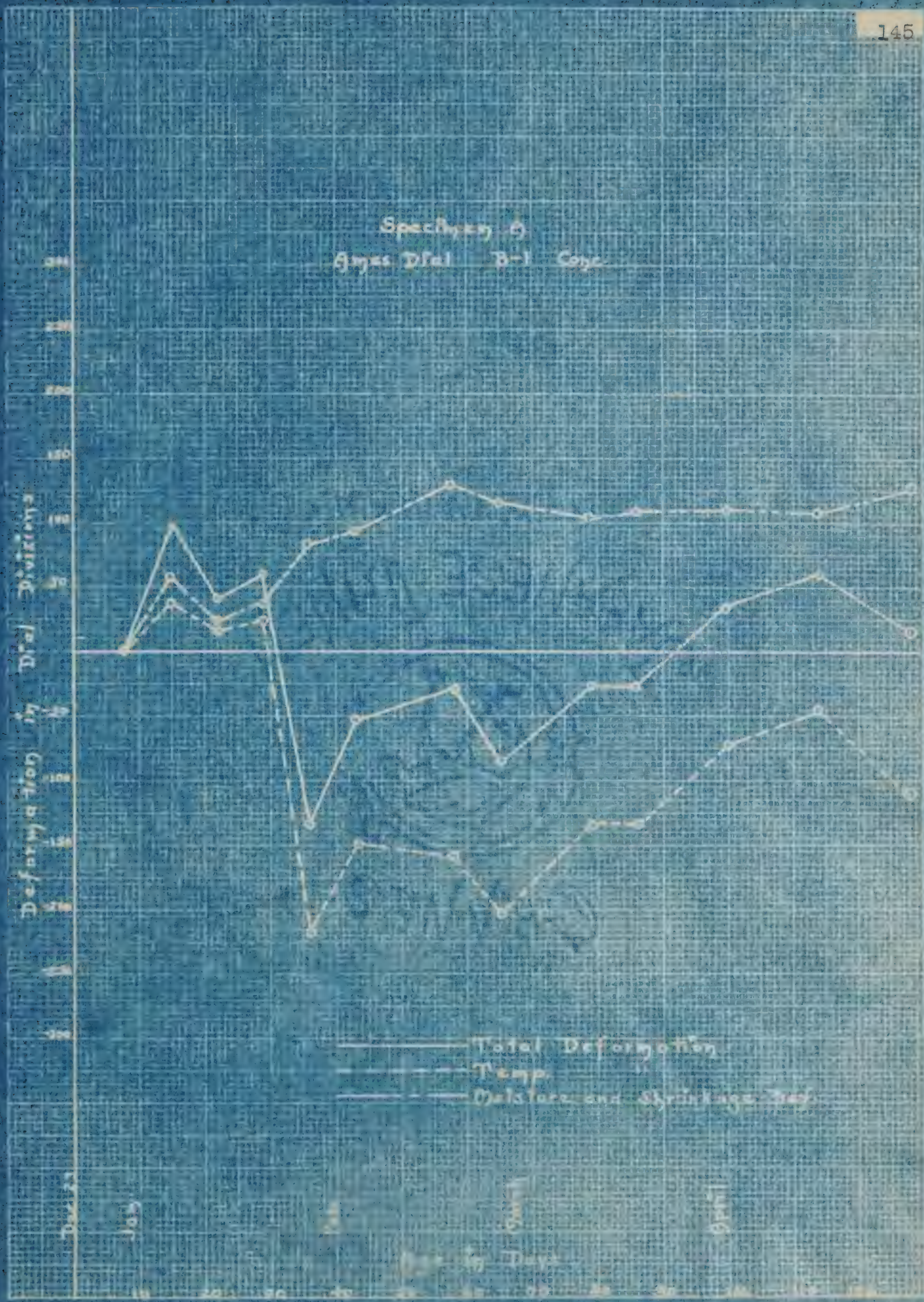

Specimen A
Amce Dial A-2 (Conc)
Deformation in Dial Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def.
Dec. 15
Jan.
Feb.
March
April
Age in Days

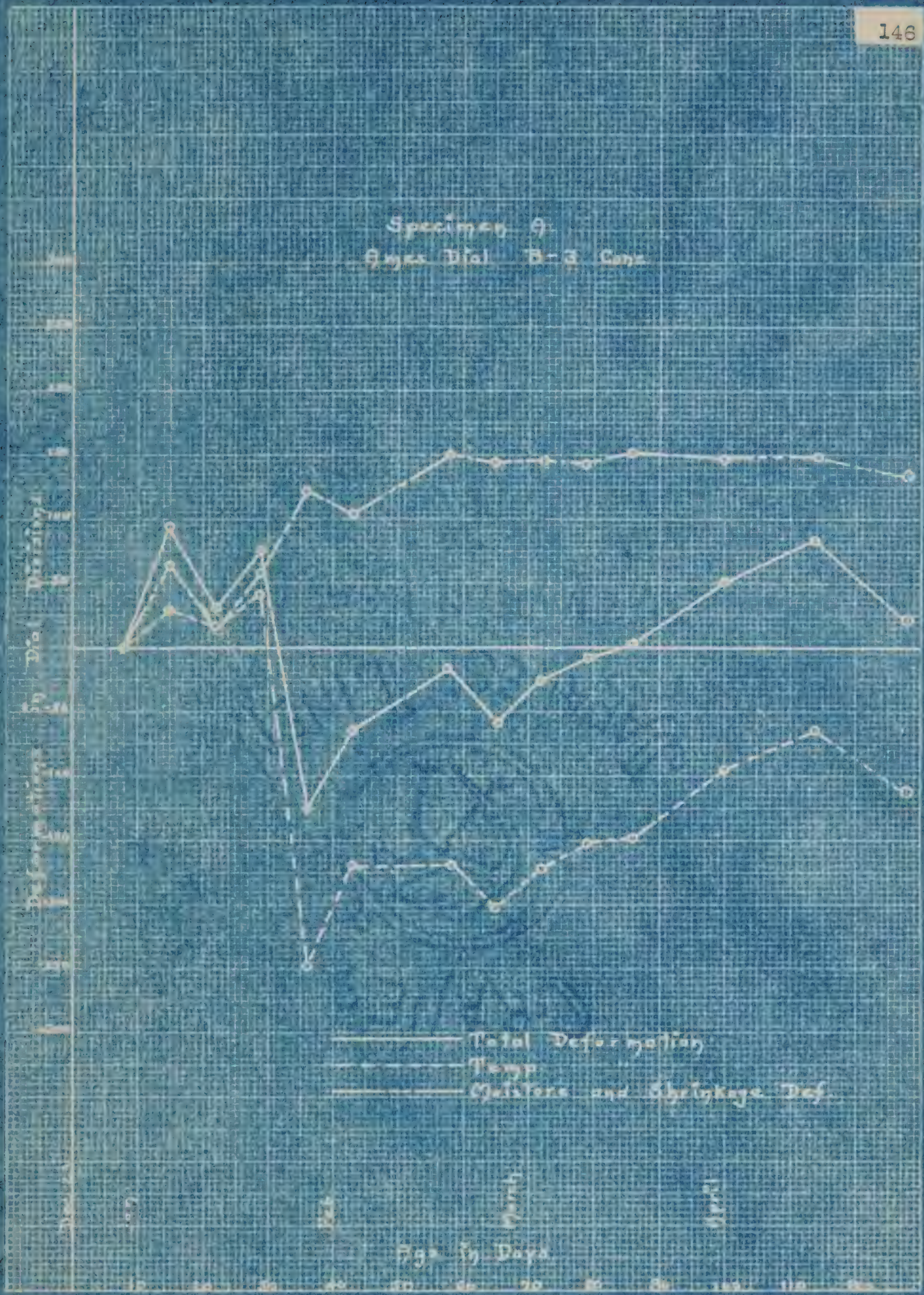

Specimen A
Ames Dial A-4 (Conc)
Deformation in Dial Divisions
Total Deformation
Temp
Moisture and Shrinkage Def
Jan.
Feb.
March
April
Age in Days

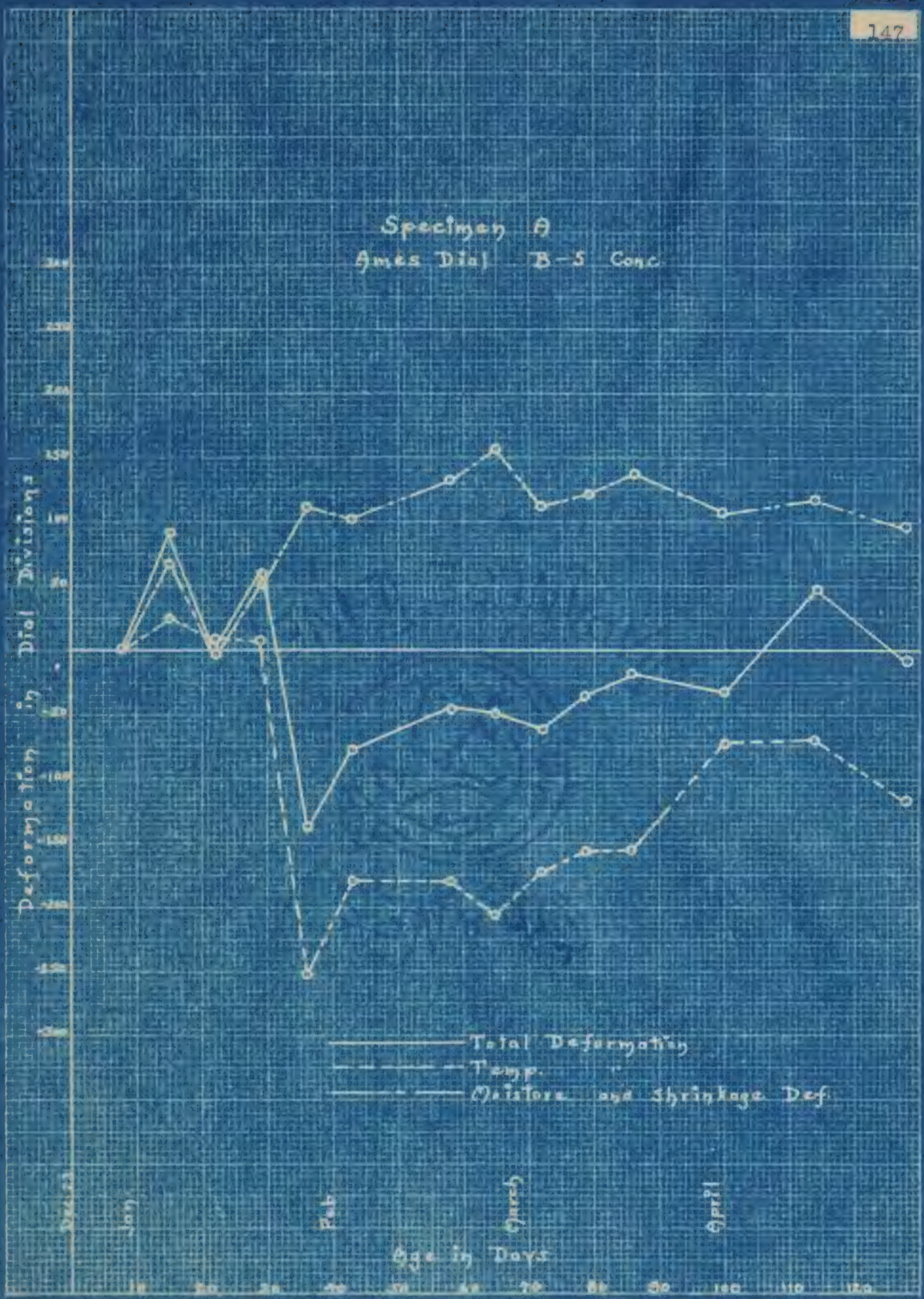
Specimen 9
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformation Dial Divisions
Age in Days
Jan
Feb
March
April

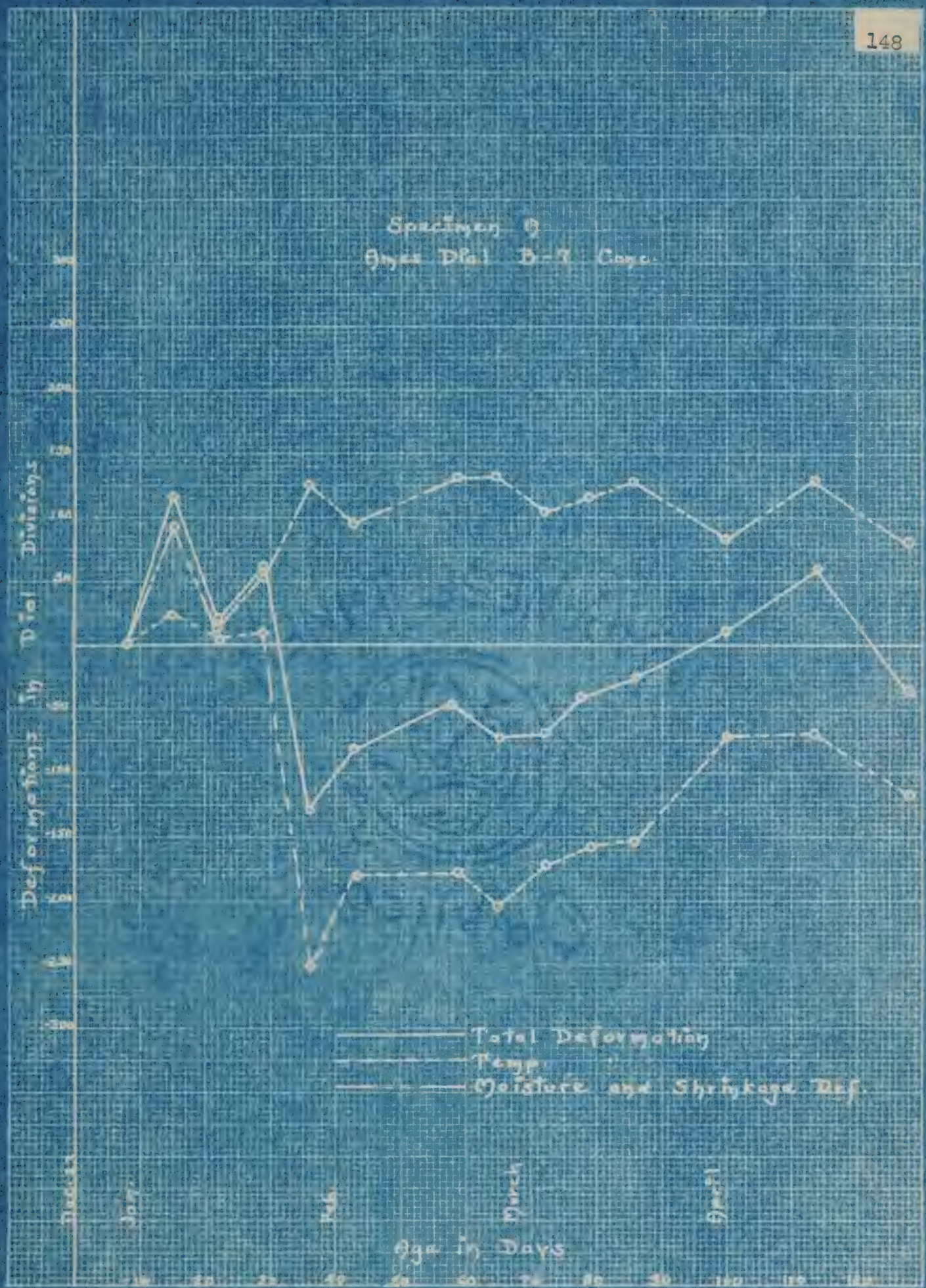

Specimen 9
Ames Dial 9-8 (Conc.)
Deformations in Dial Divisions
Total Deformations
Temp "
Moisture and Shrinkage Def.
Dec.
Jan.
Feb.
March
April
Age in Days

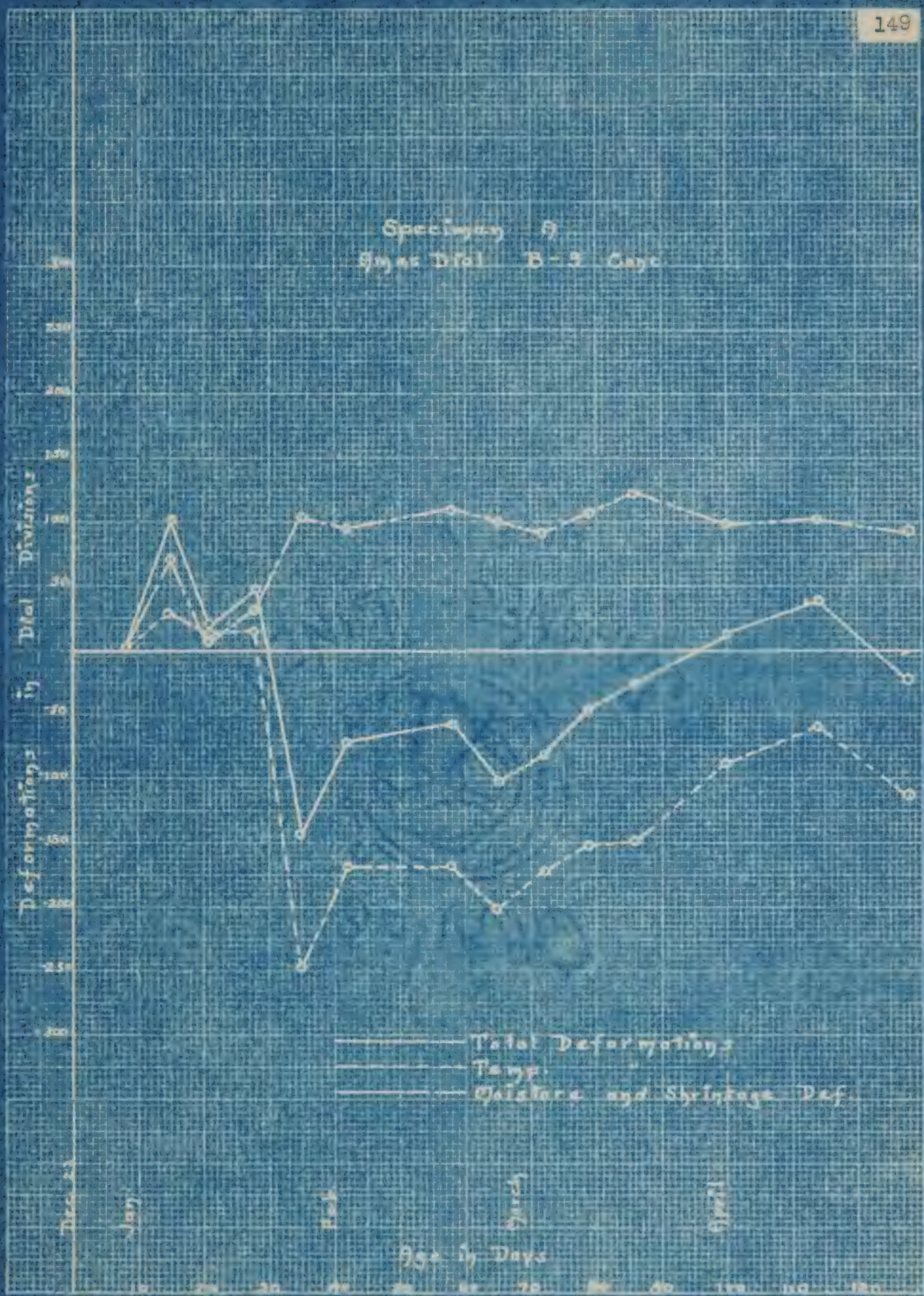

Specimen 9
Gages Dial 8-10 (Conc.)
Deformations by Dial Divisions
Total Deformations
Temp. "
Mutative and Shrinkage Def
Dec. 28
Jan.
Feb.
March
April
Age in Days

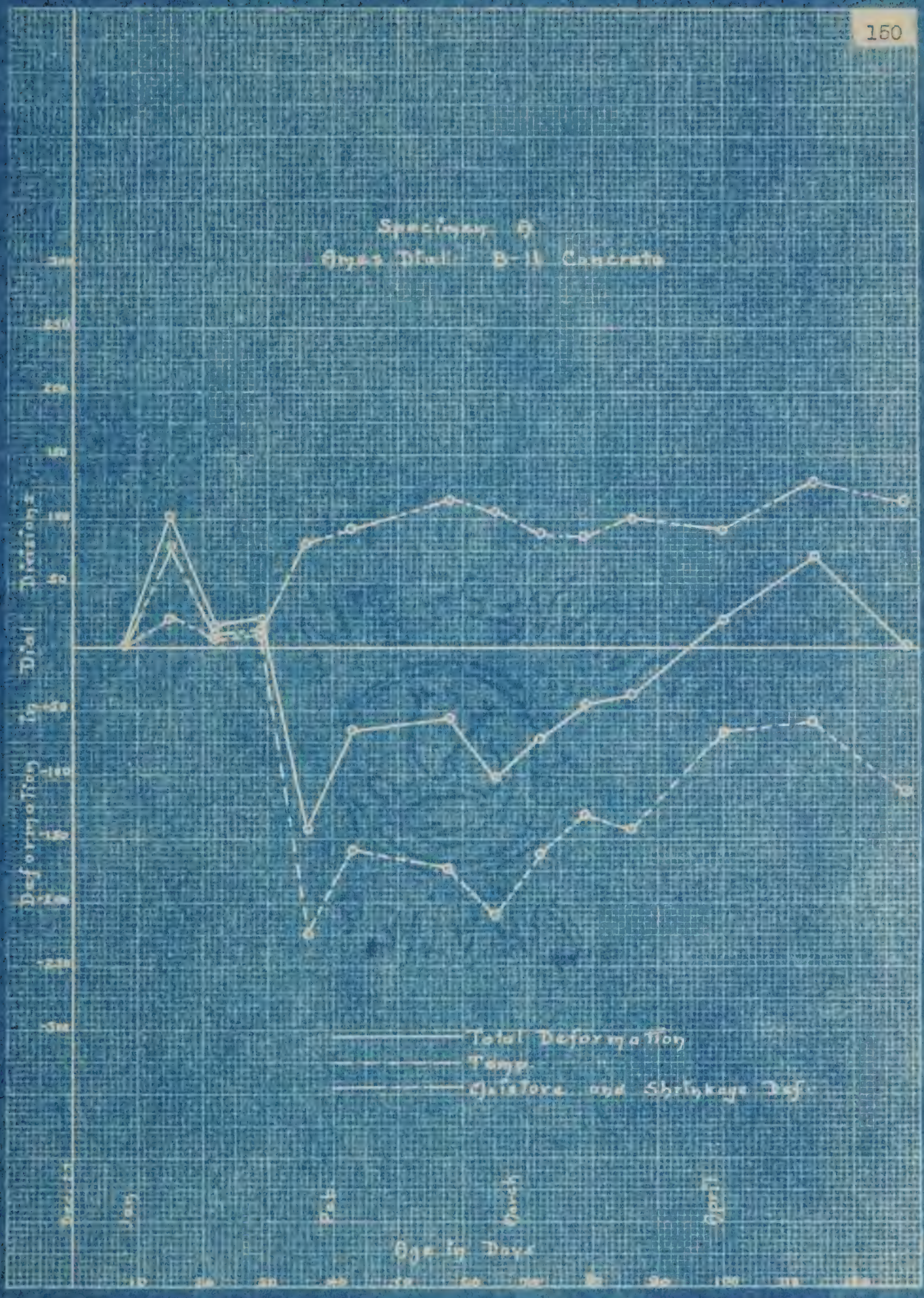

Specimen A
Ayres Dial B-1 Cycle
Deflection (Div) in Dial Divisions
Total Deformation
Temp.
Deflection and Shrinkage Def.

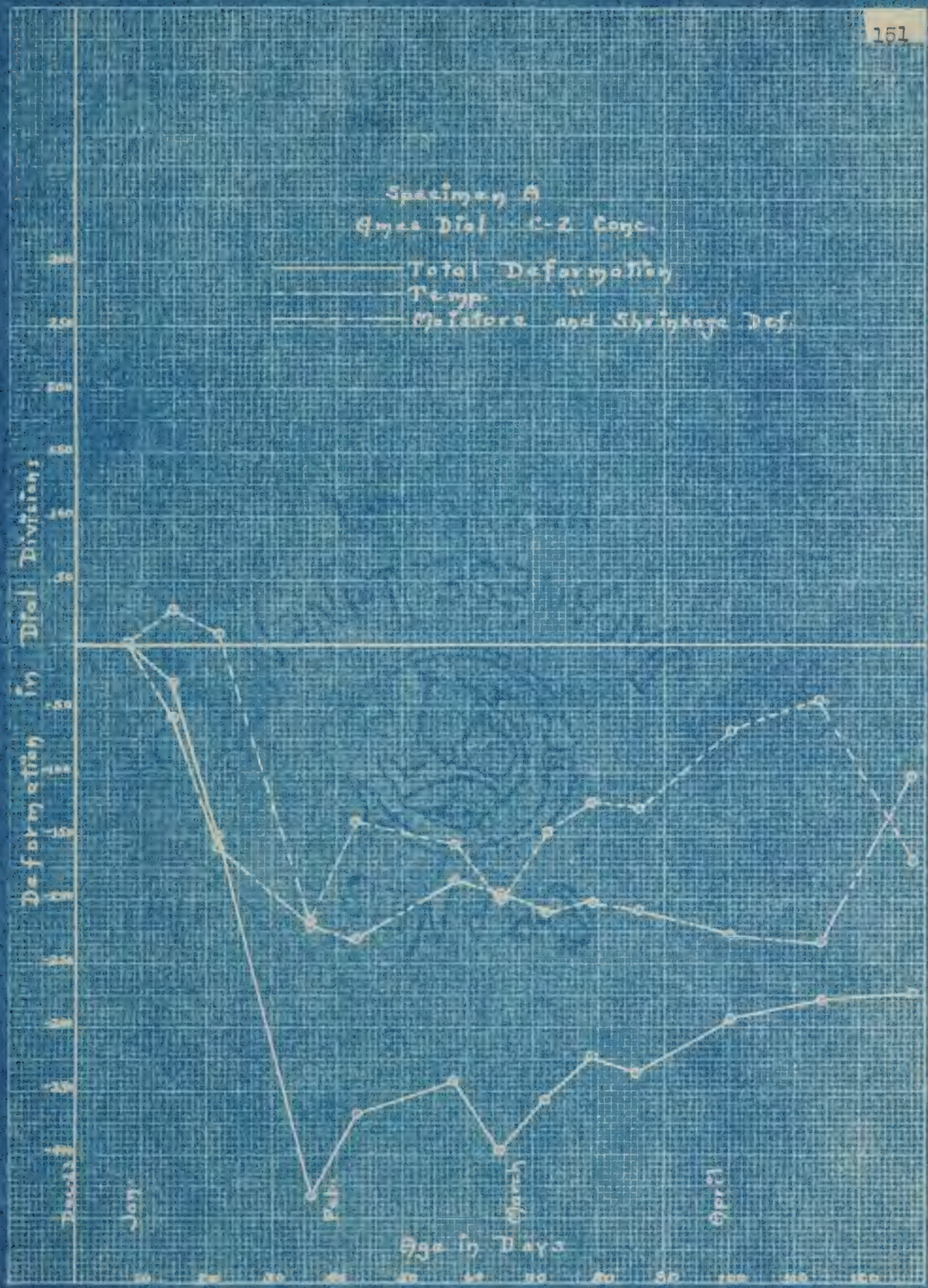

Specimen 9
Ayer Dial B-3 Conc.
Total Deformation
Temp.
Creep Def.
Shrinkage Def.
Age in Days

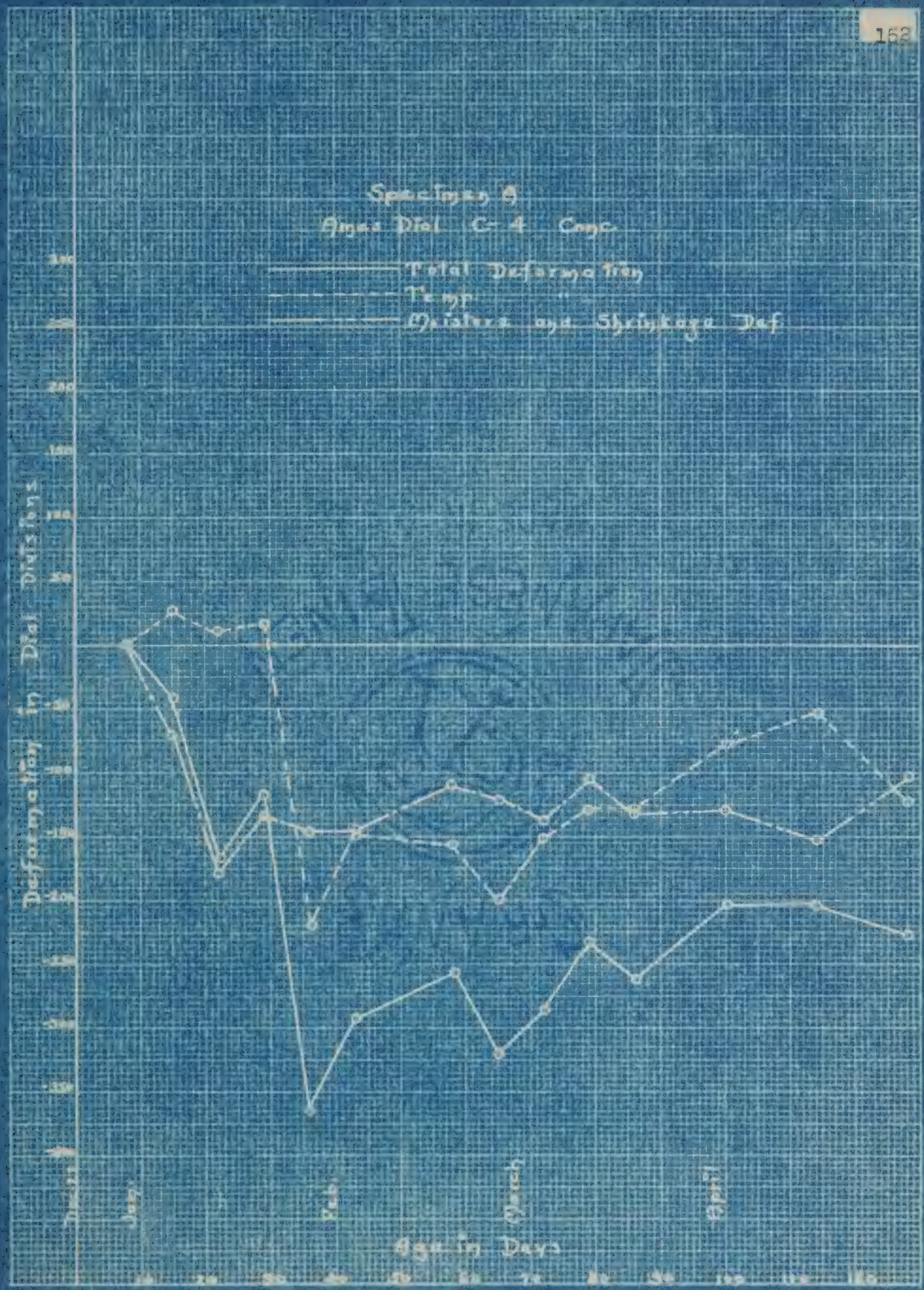

Specimen A
Ames Dial B-5 Conc
Deformation in Dial Divisions
Total Deformation
Temp.
Moisture and Shrinkage Def
Jan.
Feb.
March
April
Age in Days


Specimen 8
Total Deformations in Divisions
Total Deformations
Temp.
Moisture and Shrinkage Def.
Jan.
Feb.
March
April
Age in Days

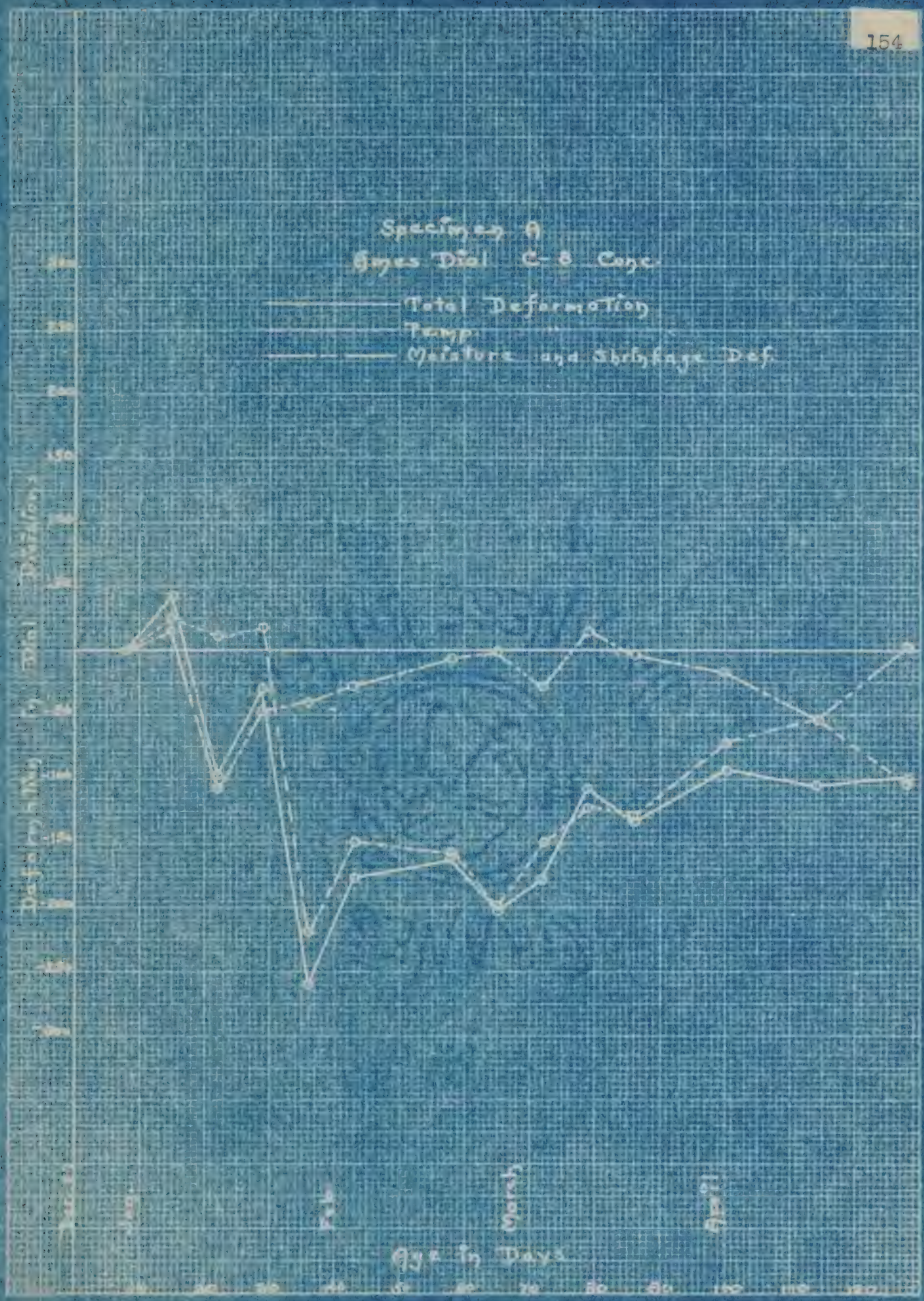

Specimen 9
Dial B-9 Gage
Dial Divisions
Total Deformations
Temp.
Moisture and Shrinkage Def.
Age in Days

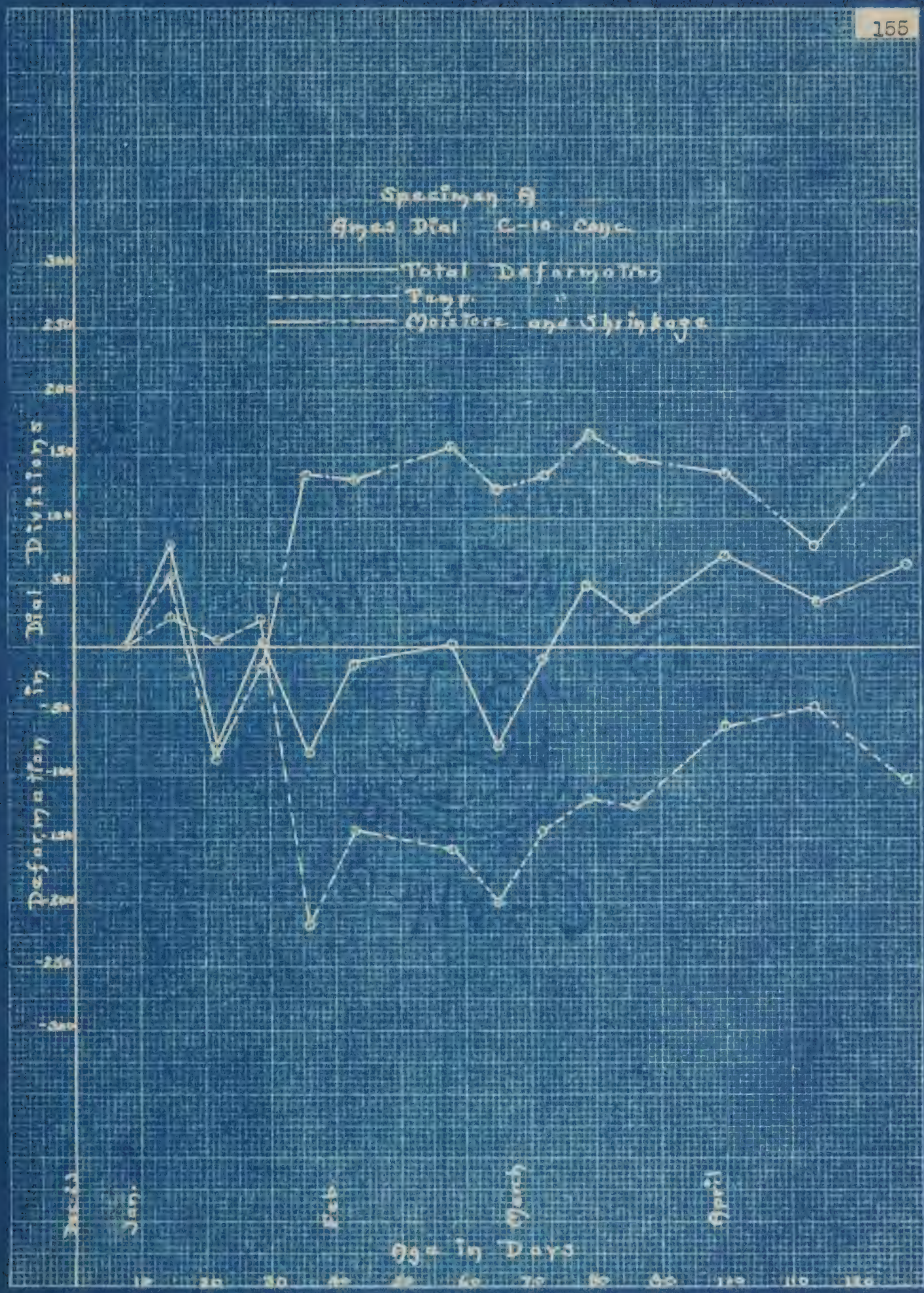

Specimen 6
Ayer's Dial B-11 Concrete
Deformation in Dial Division
Total Deformation
Temp
Shrinkage Def
Shrinkage Def
Jan.
Feb.
March
April
Age in Days

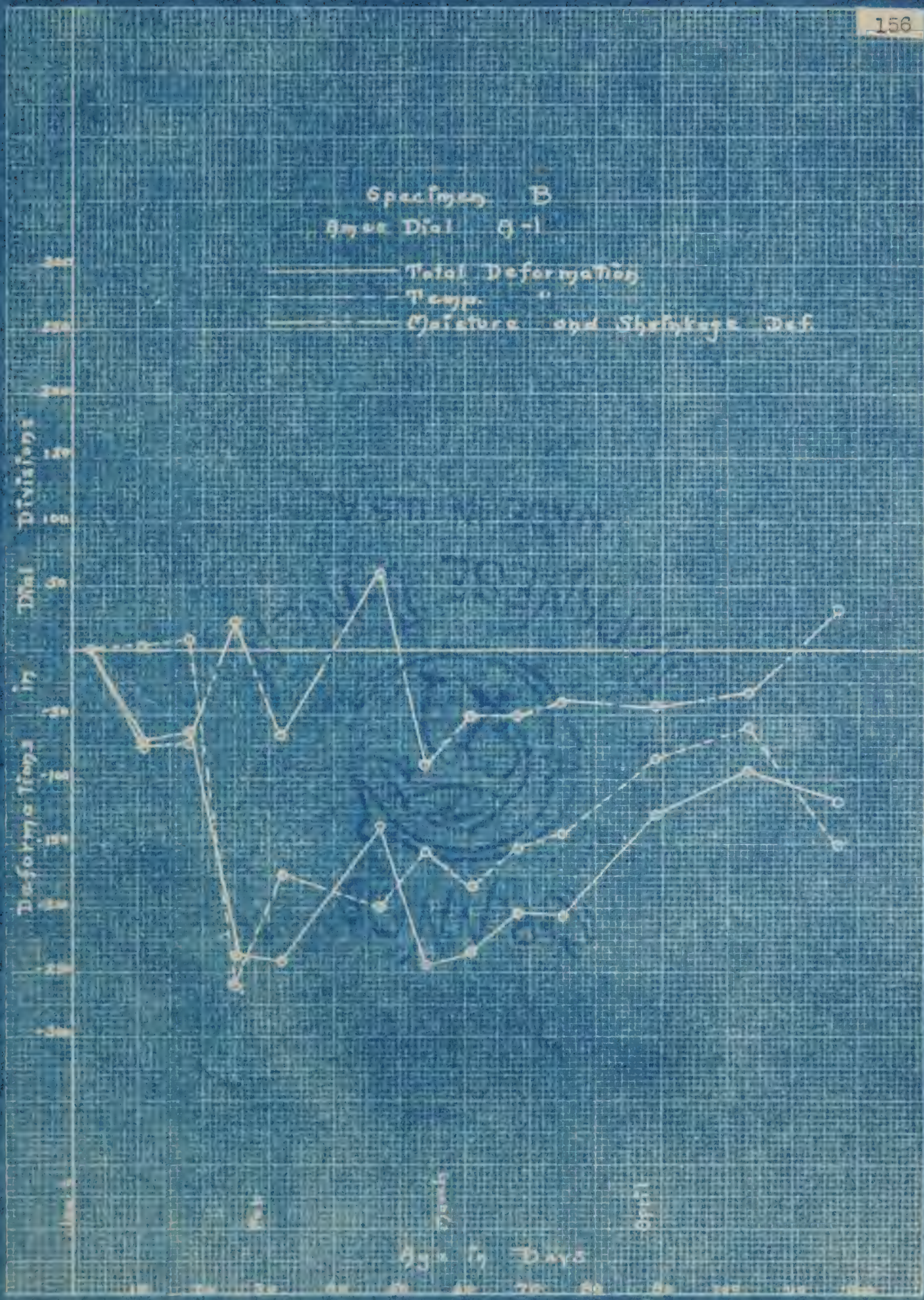

Specimen A
Ames Dial C-2 Conc.
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformation in Dial Divisions
Age in Days
Jan.
Feb.
March
April

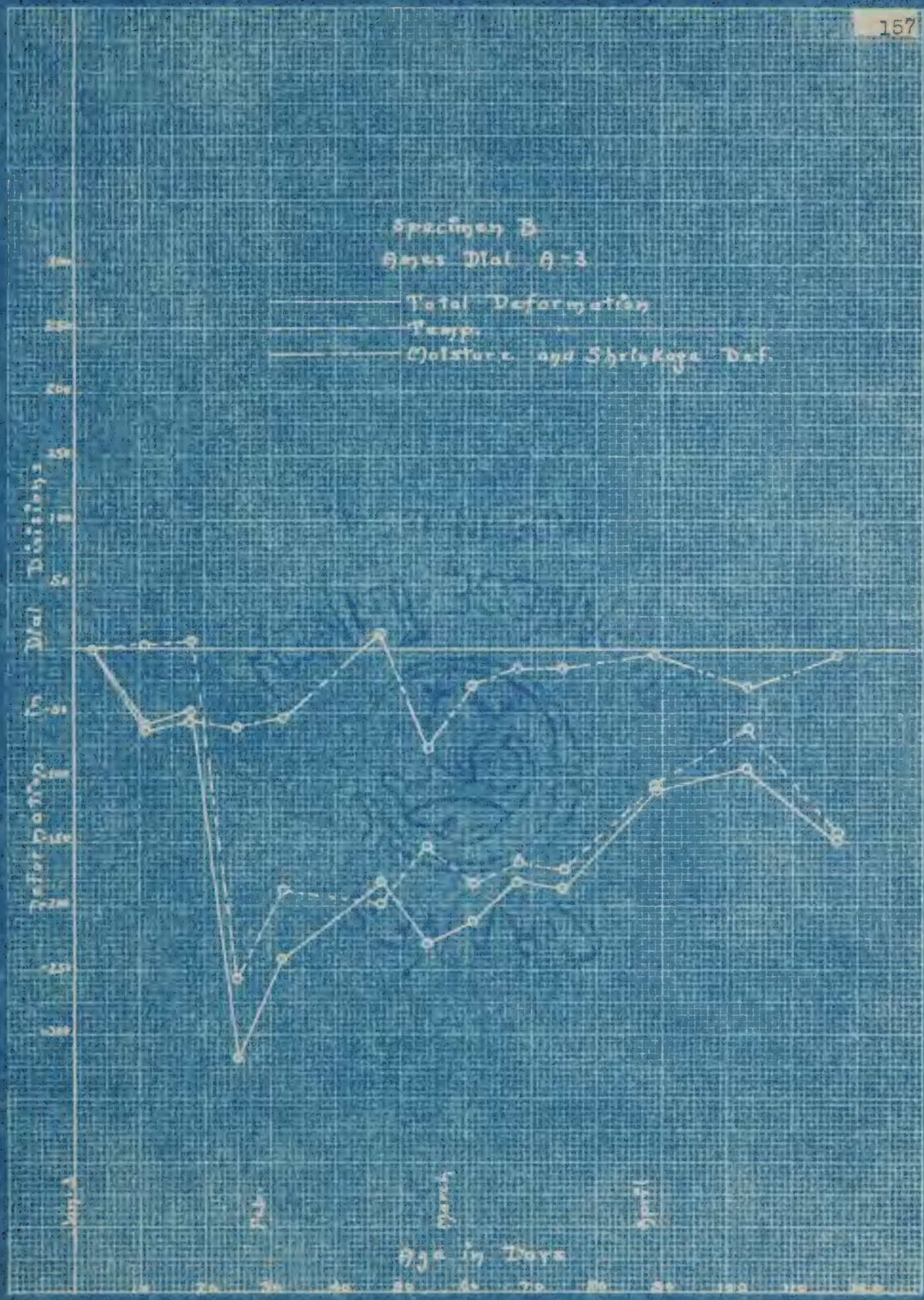

Specimen 9
Ages Diel C-4 Comp
Total Deformation
Temp
Moisture and Shrinkage Def
Deformation in Dial Divisions
Jan.
Feb.
March
April
Age in Days

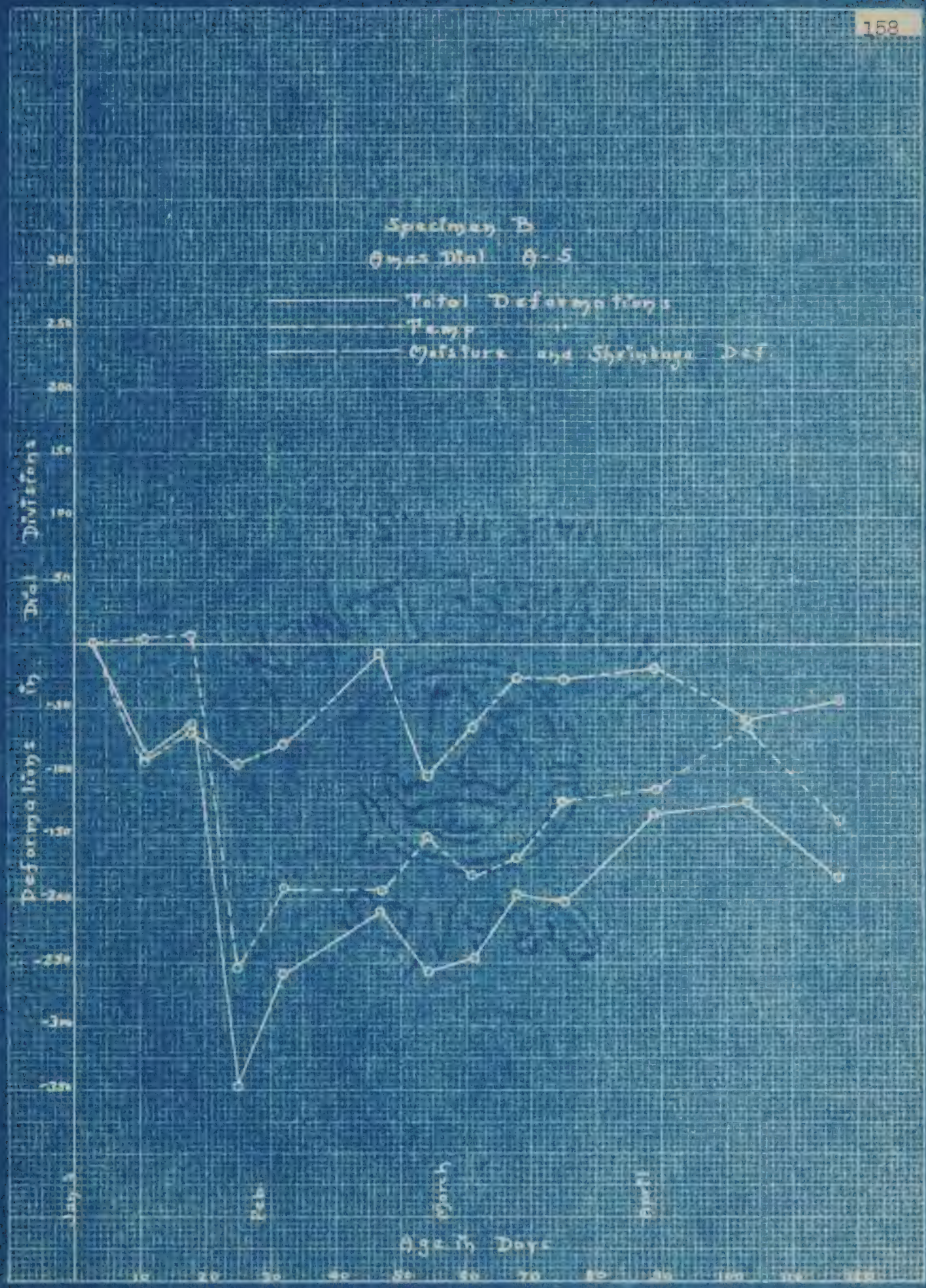
Specimen 9
Ames Dial C-6 Conc.
Total Deformation
Temp.
Moisture and Shrinkage Def
Deformation (in. Dial 0 Reading)
Jan.
Feb.
March
April
Age in Days

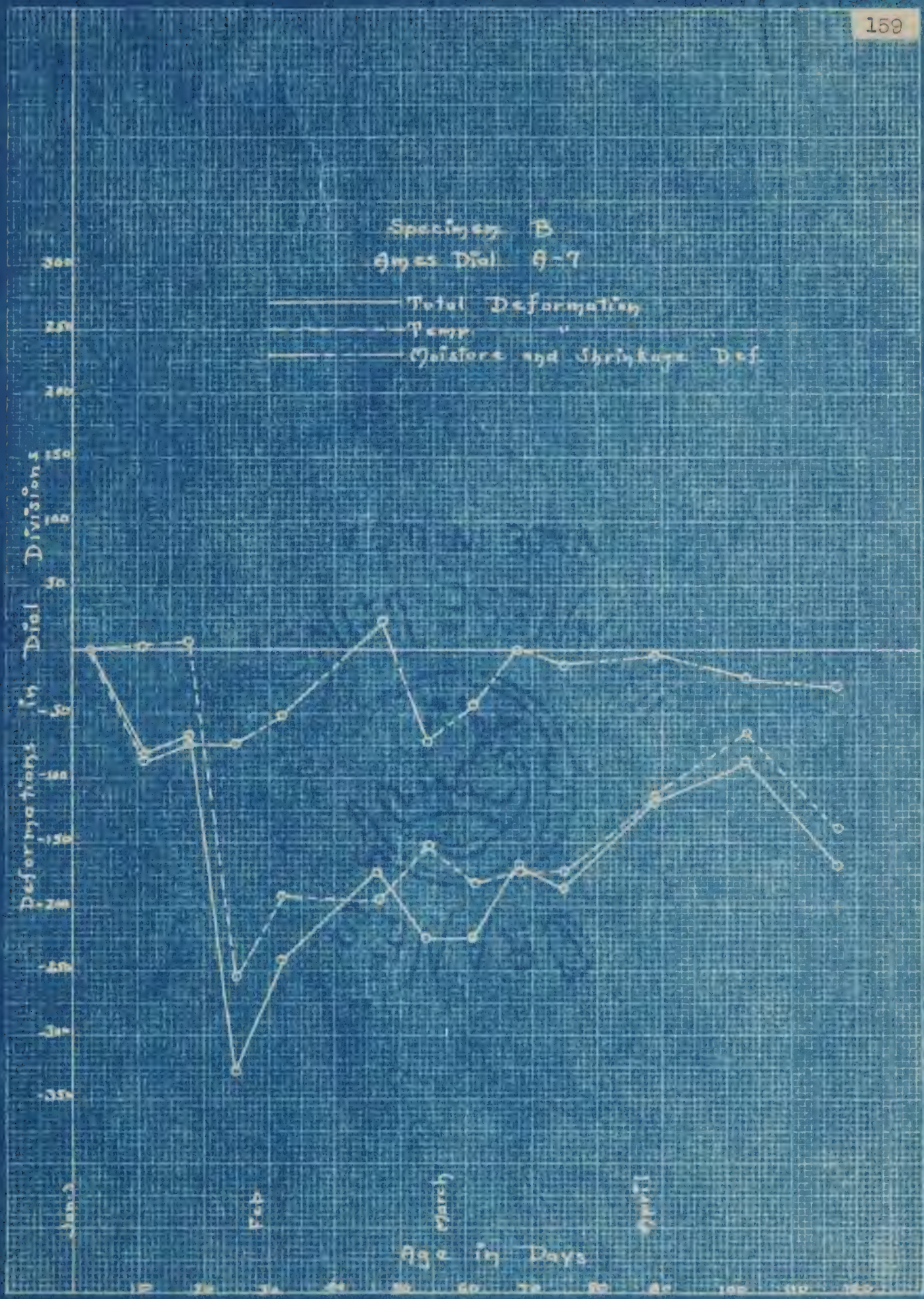

Specimen A
Ayres Dial C-8 Conc
Total Deformation
Temp
Moisture and Shrinkage Def
Dial Deflection
Feb
March
April
Age in Days

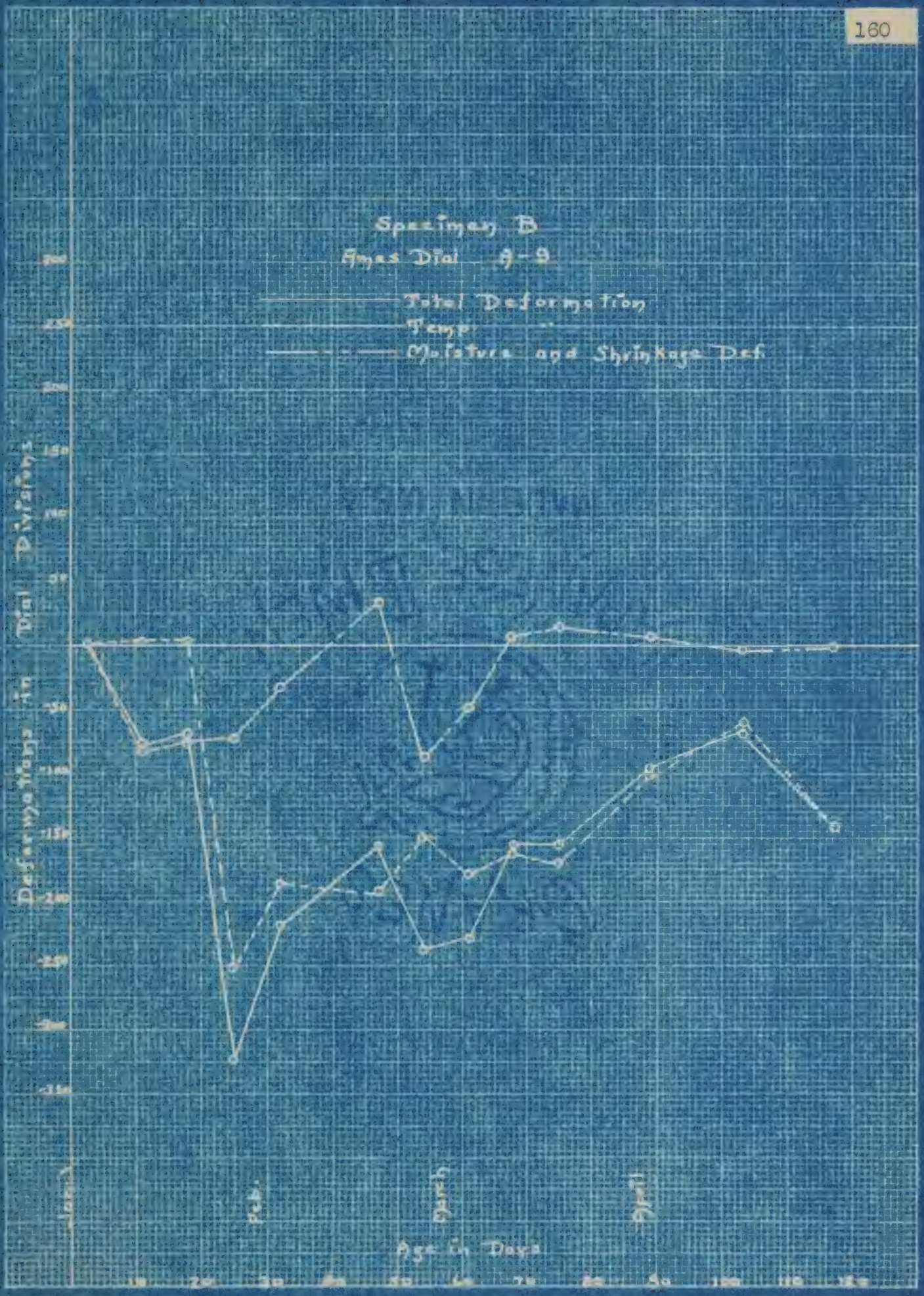

Specimen A
Gages Dial C-10 Case
Total Deformation
Temp.
Moisture and Shrinkage
Deformation in Dial Divisions
Jan.
Feb.
March
April
Age in Days

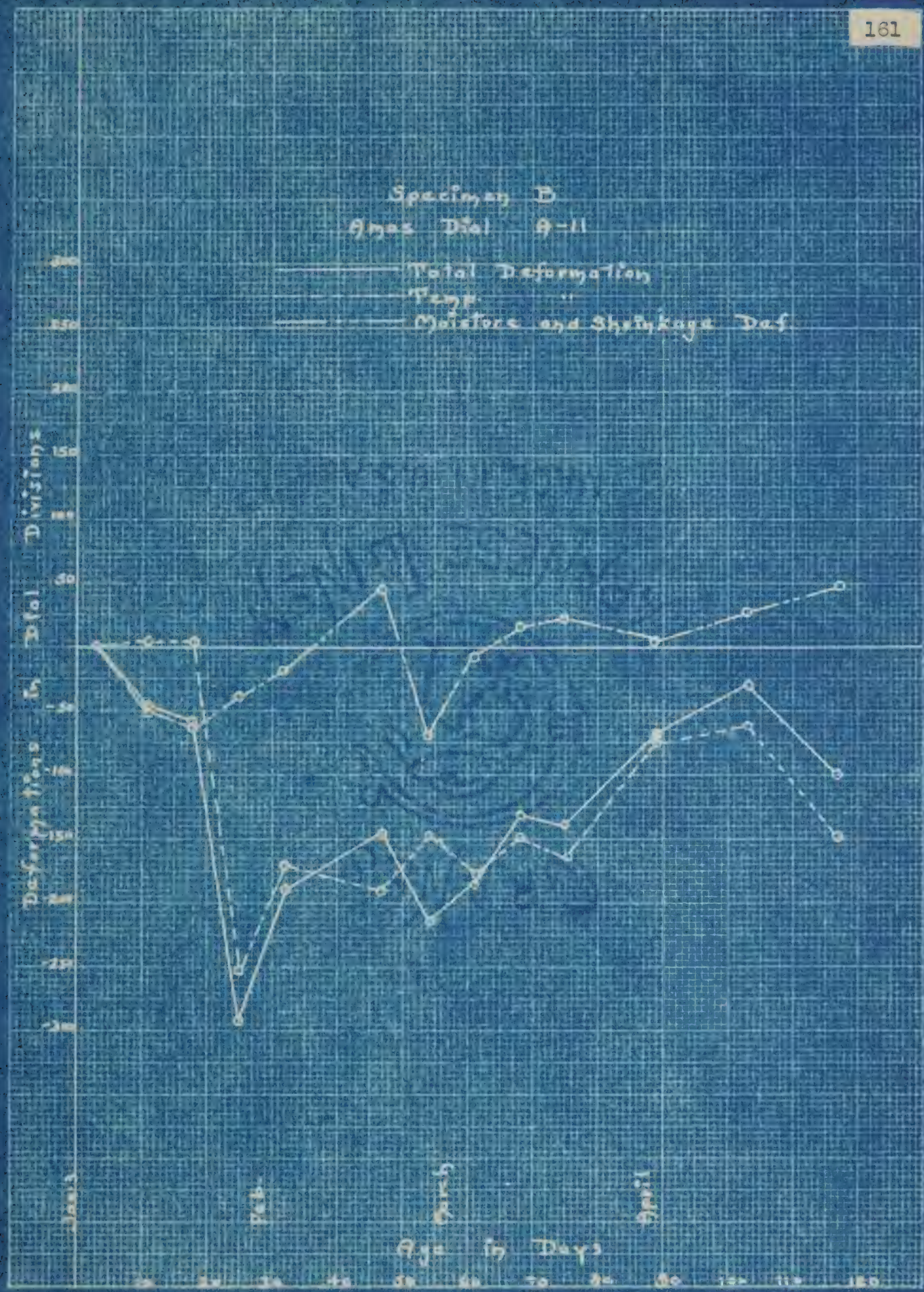

Specimen B
Gage Dial G-1
Total Deformation
Temp.
Moisture and Shrinkage Def
Deformations in Dial Divisions
Days

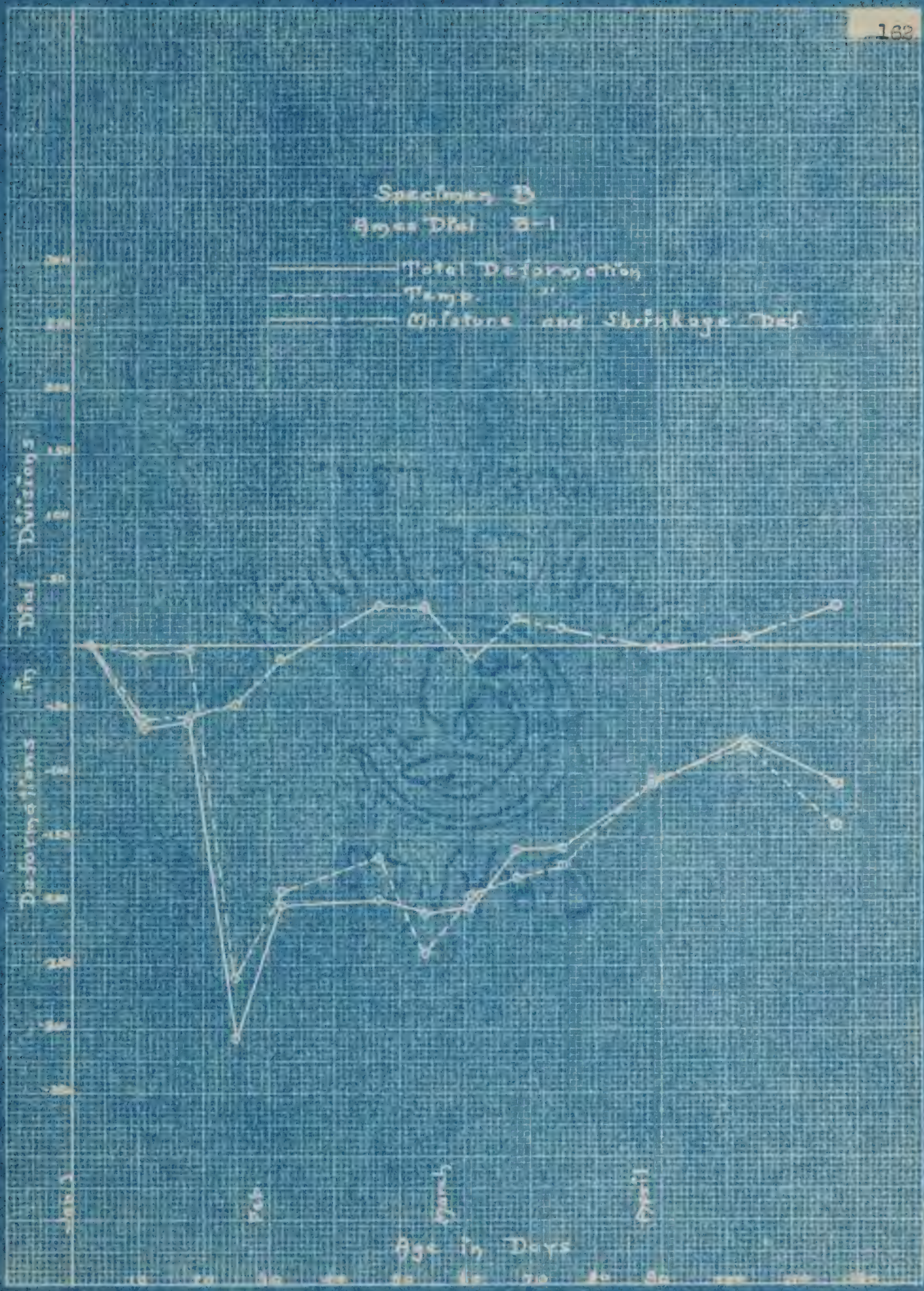

Specimen B
Ames Dial A-3
Total Deformation
Temp.
Moisture and Shrinkage Def.
Dial Divisions
Feb.
March
April
Age in Days

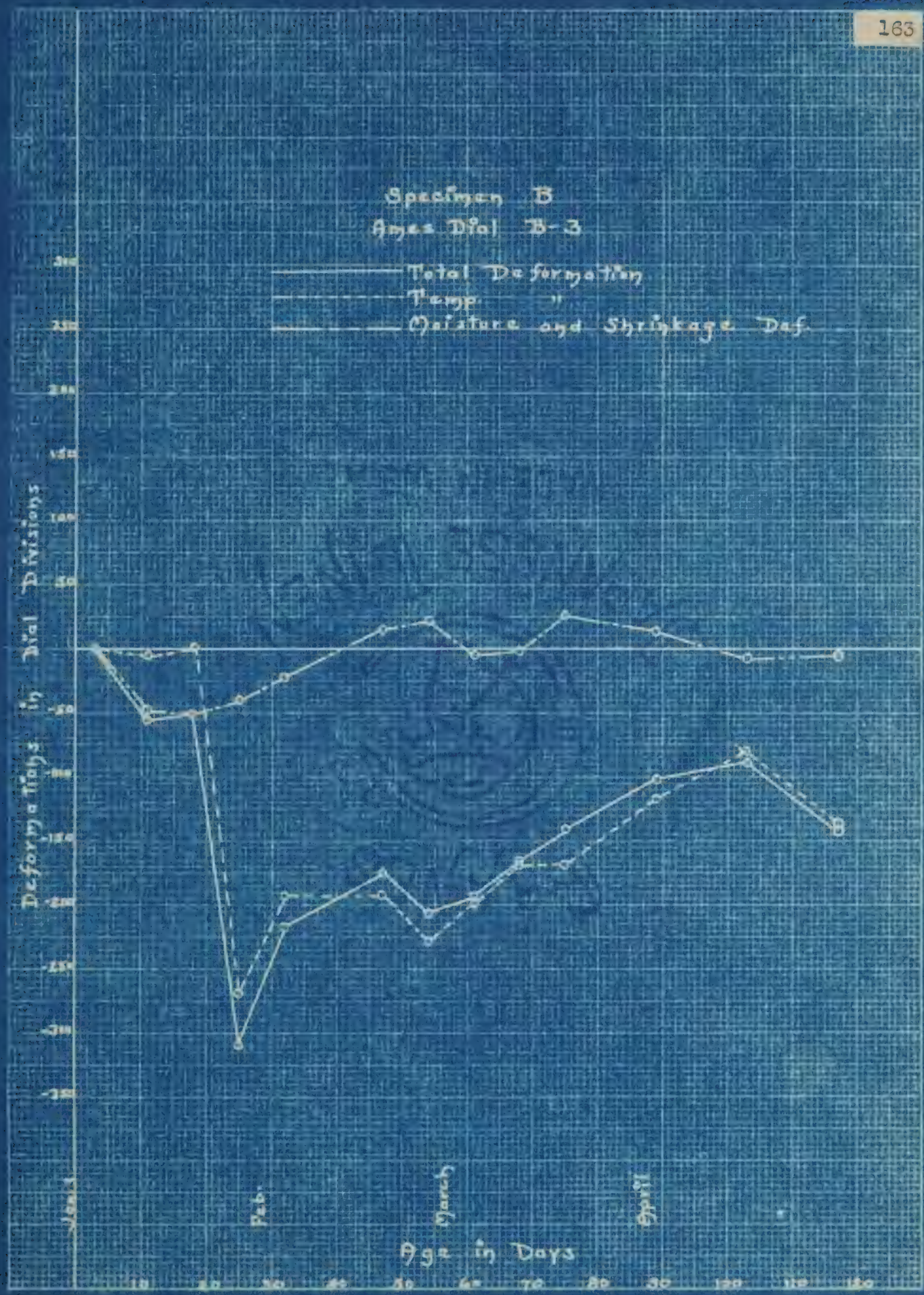

Specimen B
Ayres Dial A-5
Total Deformations
Temp
Moisture and Shrinkage Def
Deformations in Dial Divisions
Age in Days
Feb
March
April

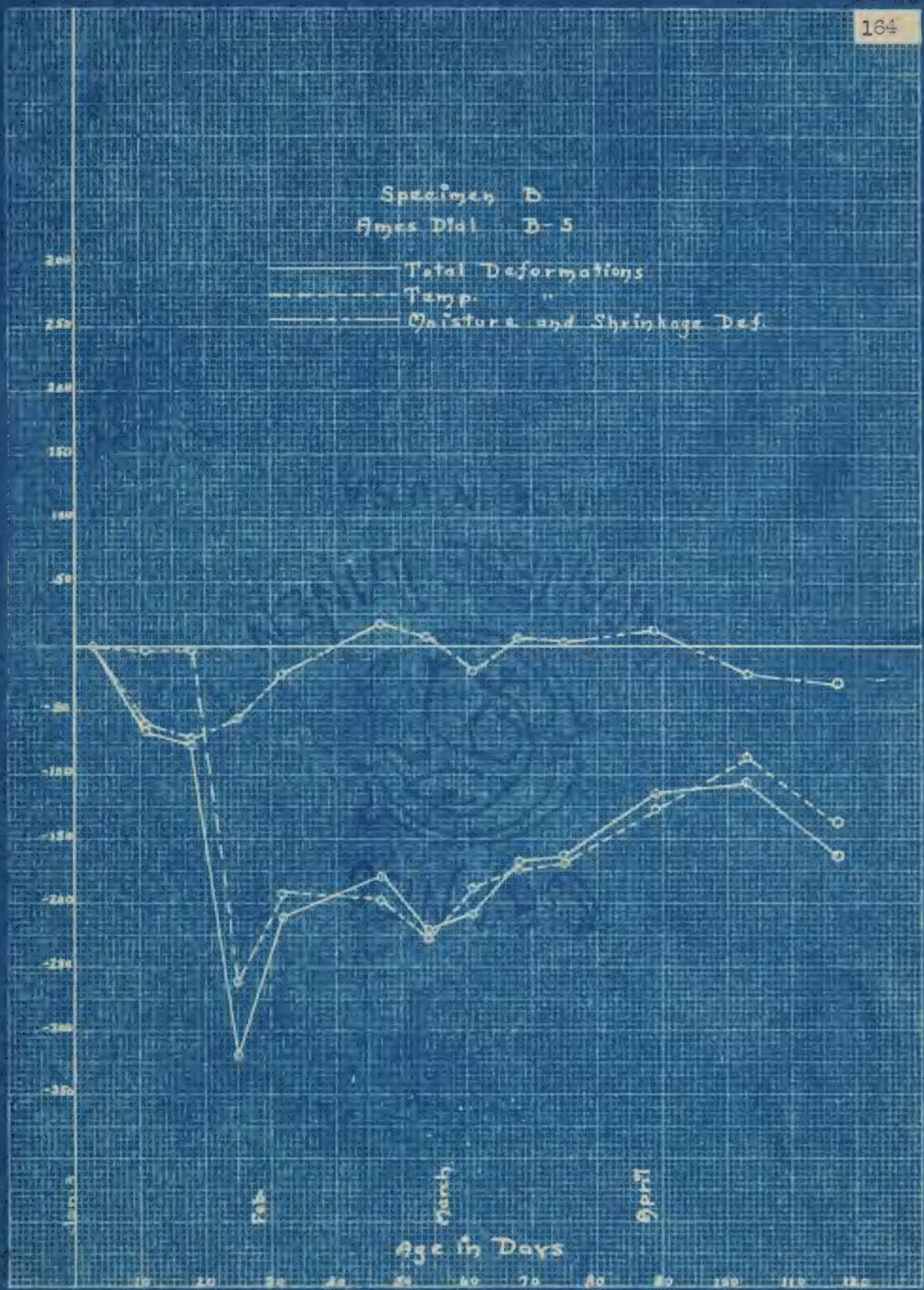

Specimen B
Gages Dial 8-7
Total Deformation
Temp
Moisture and Shrinkage Def
Deformations in Dial Divisions
Age in Days
Jan.
Feb.
March
April

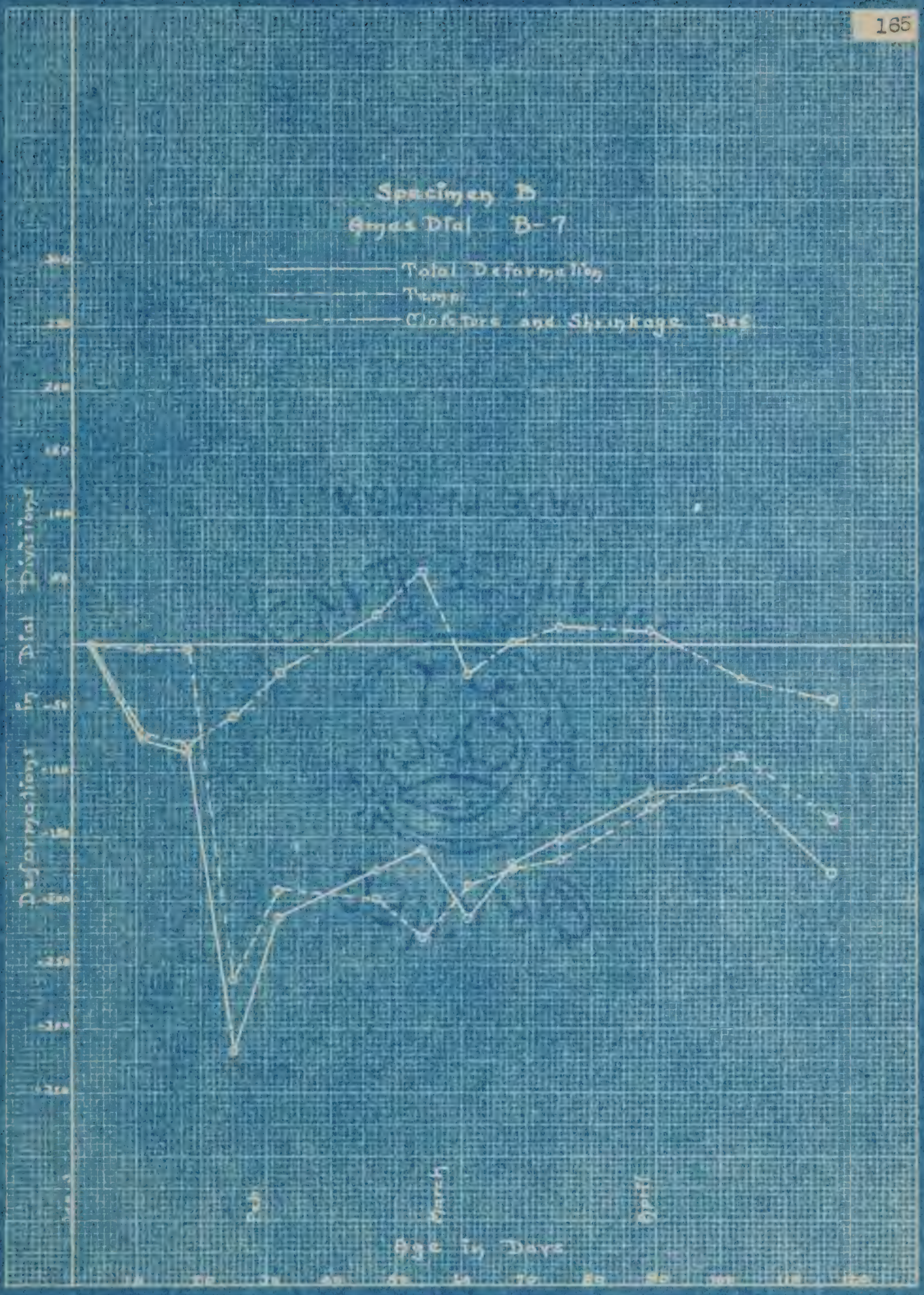

Specimen B
Ames Dial 9-9
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformations in Total Divisions
Feb.
March
April
Age in Days


Specimen B
Ames Dial A-11
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformations in Total Divisions
Feb.
March
April
Age in Days

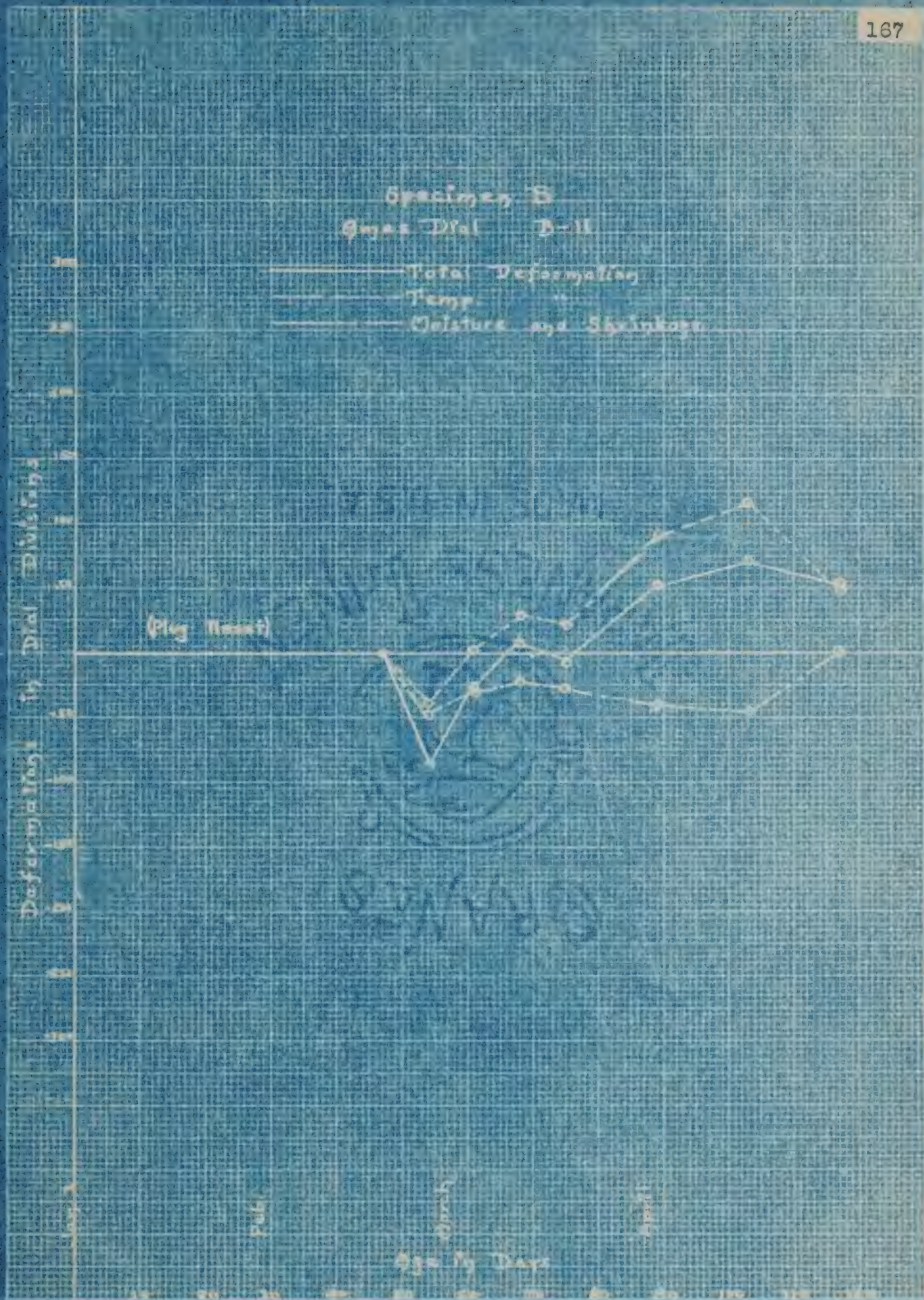

Specimen B
Ayes Dial B-1
Total Deformation
Temp.
Moisture and Shrinkage Def
Dial Divisions
Deformations in
Feb
March
April
Age in Days

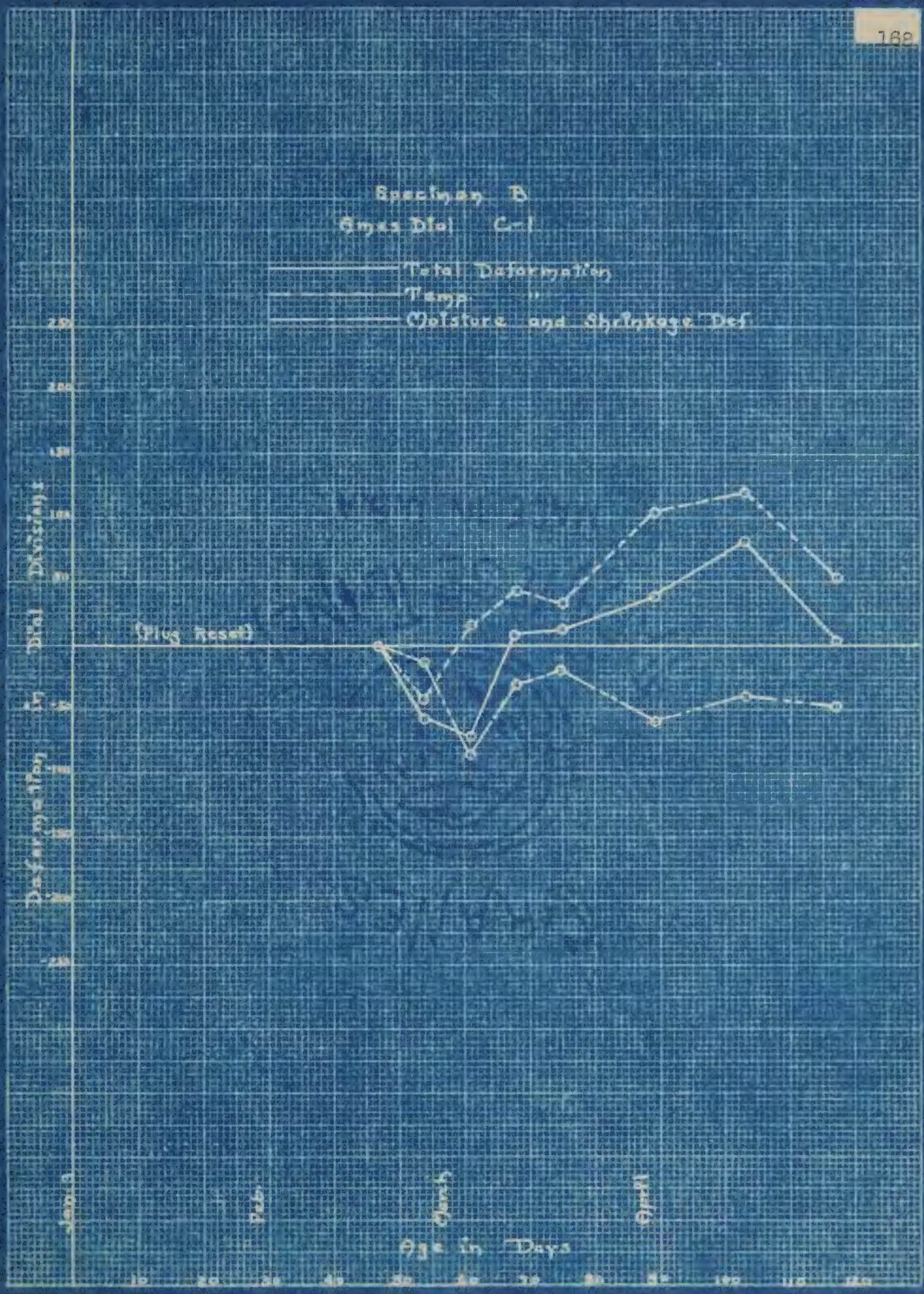

Specimen B
Ames Dial B-3
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Deformations in Dial Divisions
Jan.
Feb.
March
April
Age in Days

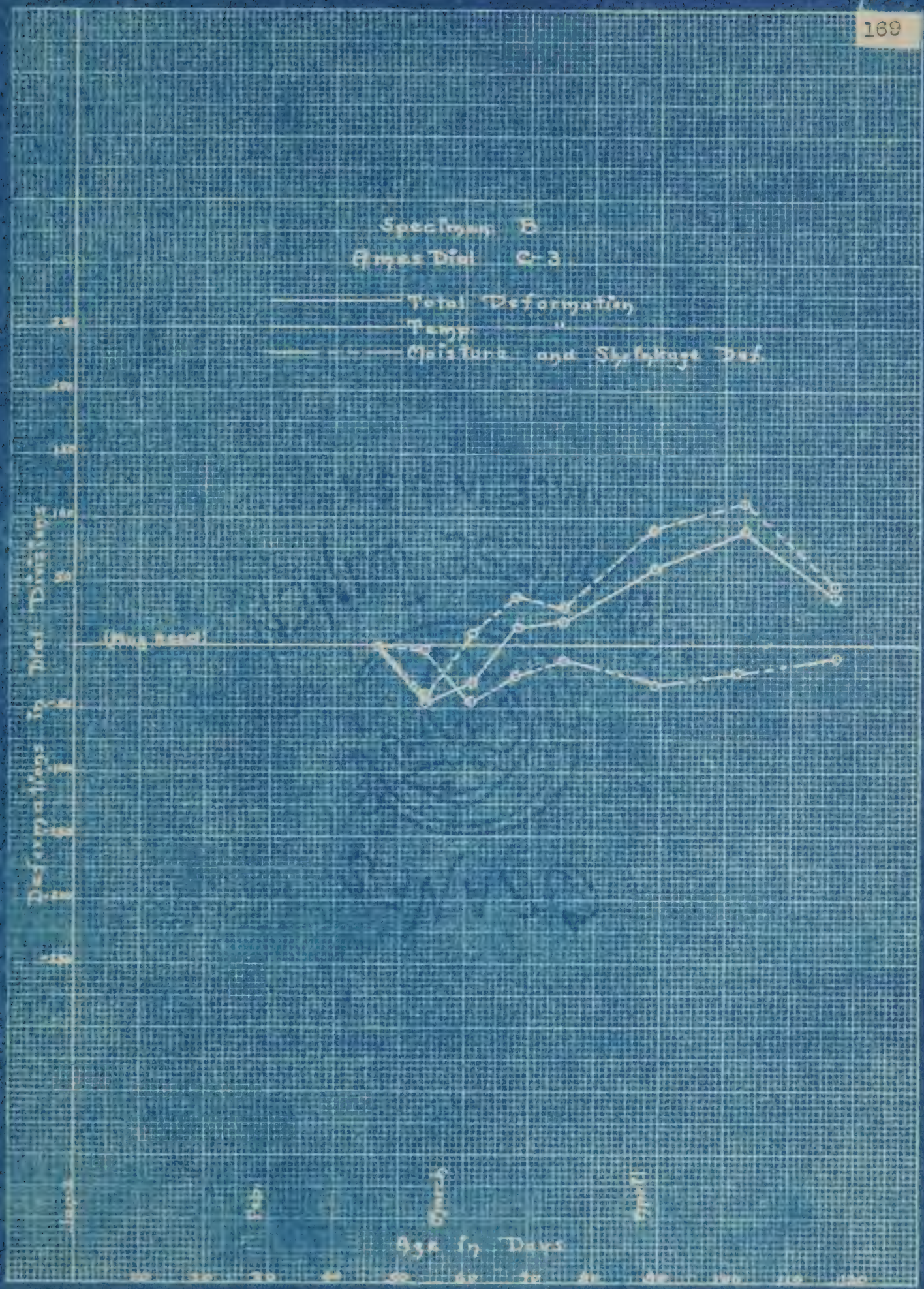

Specimen D
Ames Dial B-5
Total Deformations
Temp. "
Moisture and Shrinkage Def.
Feb.
March
April
Age in Days

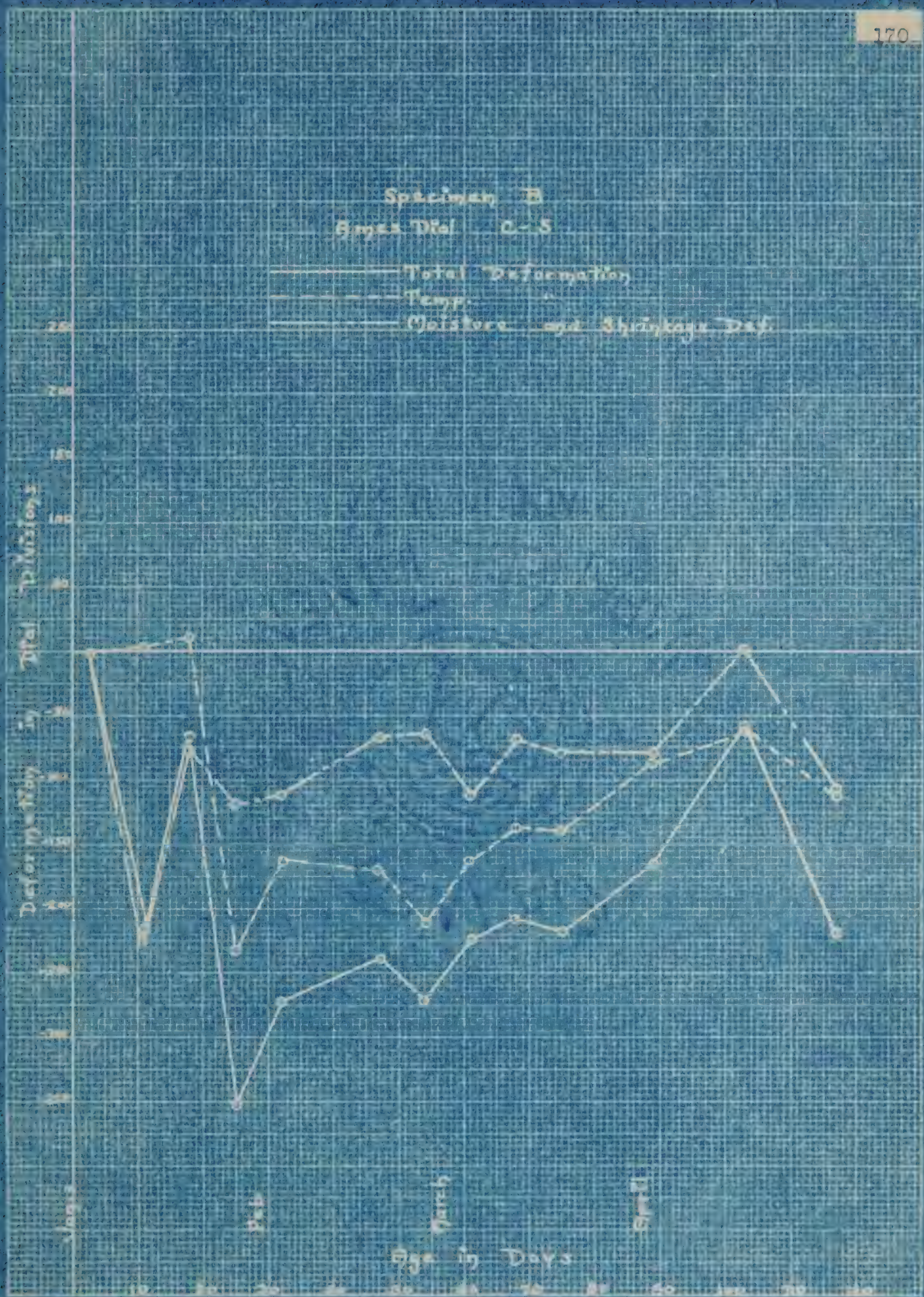

Specimen B
Gages Dial B-7
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformations in Dial Divisions
Age in Days
Feb
March
April

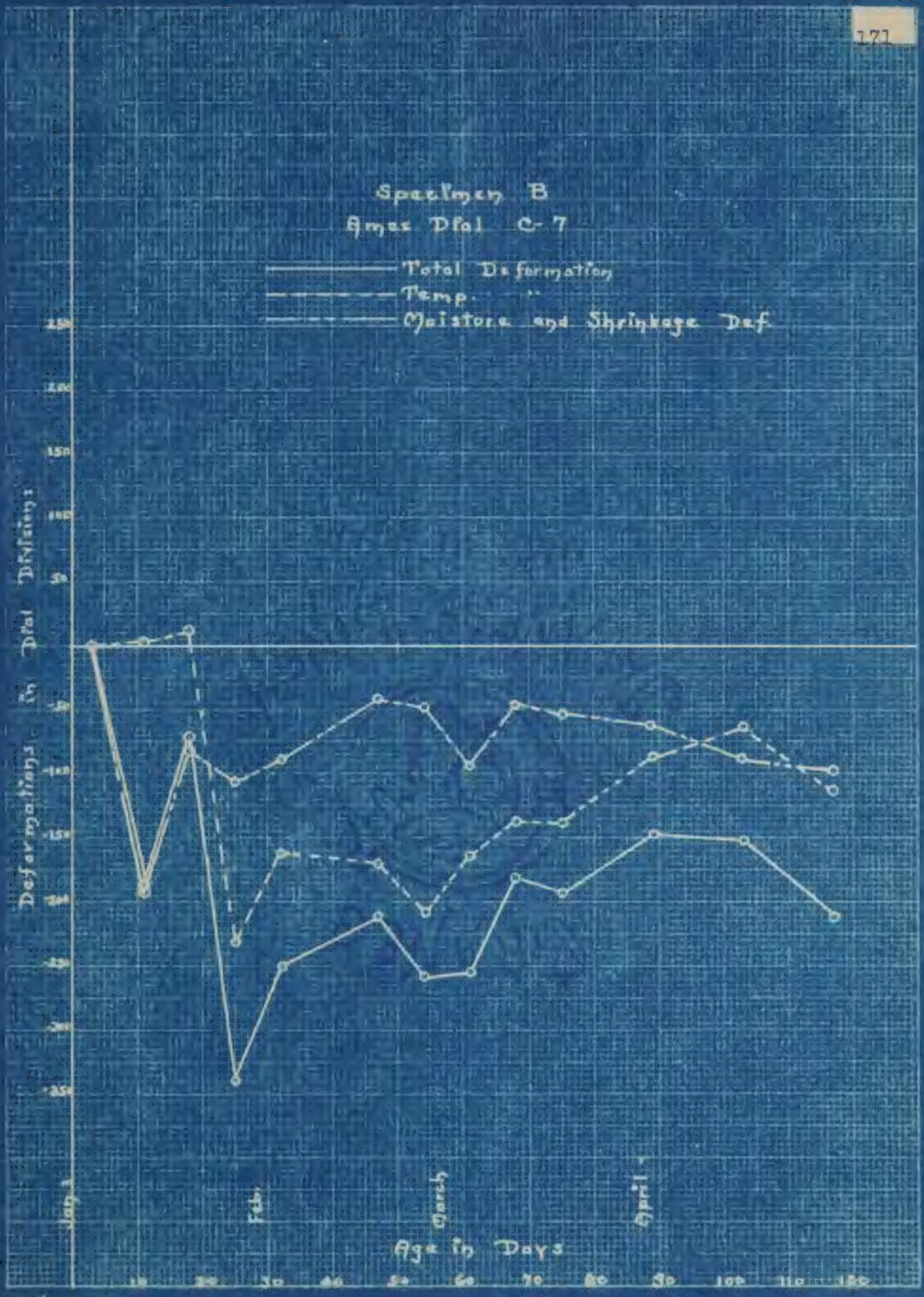
Specimen B
Gage No. B - 9
Total Deformation
Temp.
Moisture and Shrinkage Def.
Deformations in Dial Divisions
Age in Days
Feb.
March
April

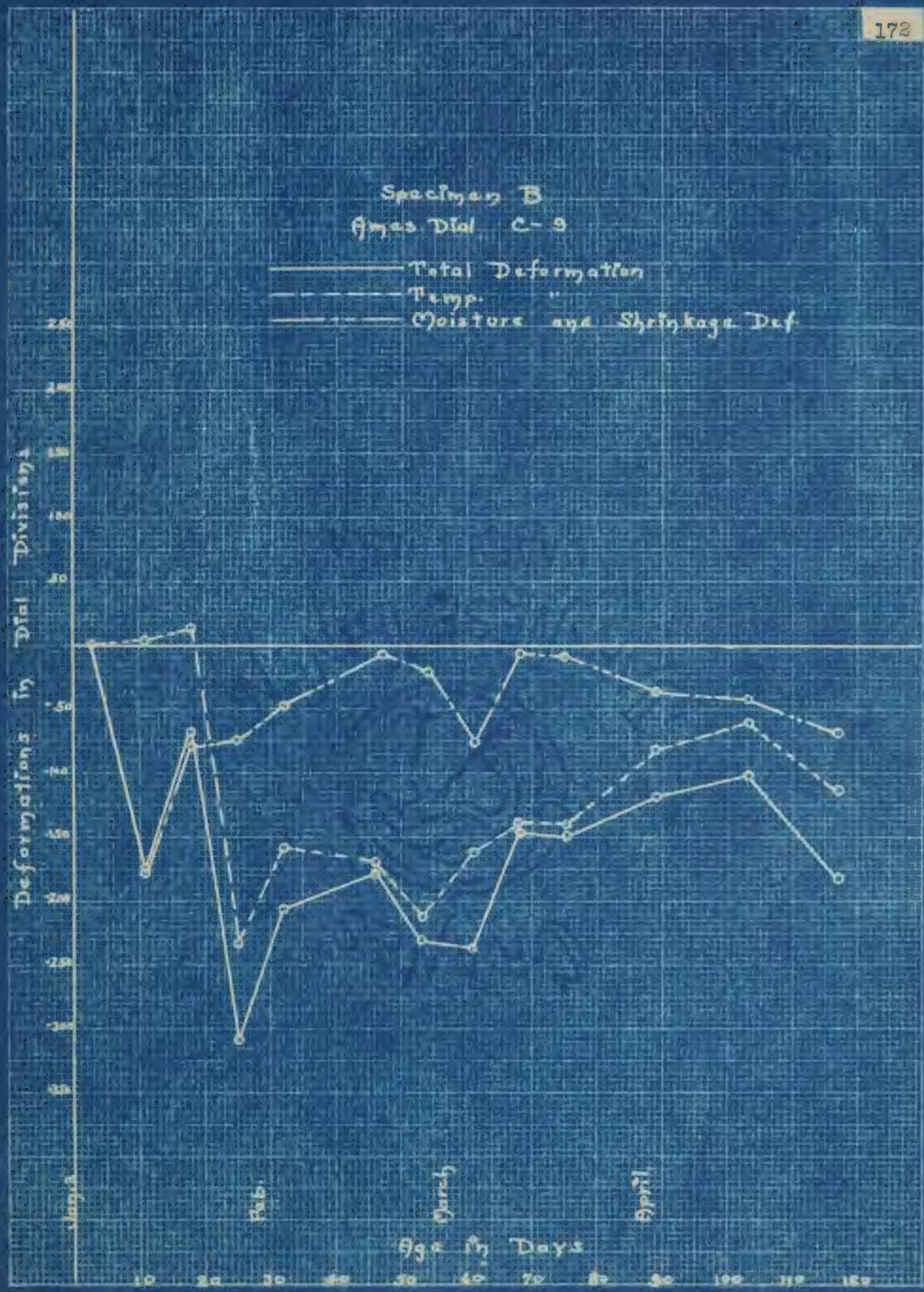

Specimen B
Gage Dial B-11
Total Deformation
Temp "
Moisture and Shrinkage
(Plug Heat)
Age in Days

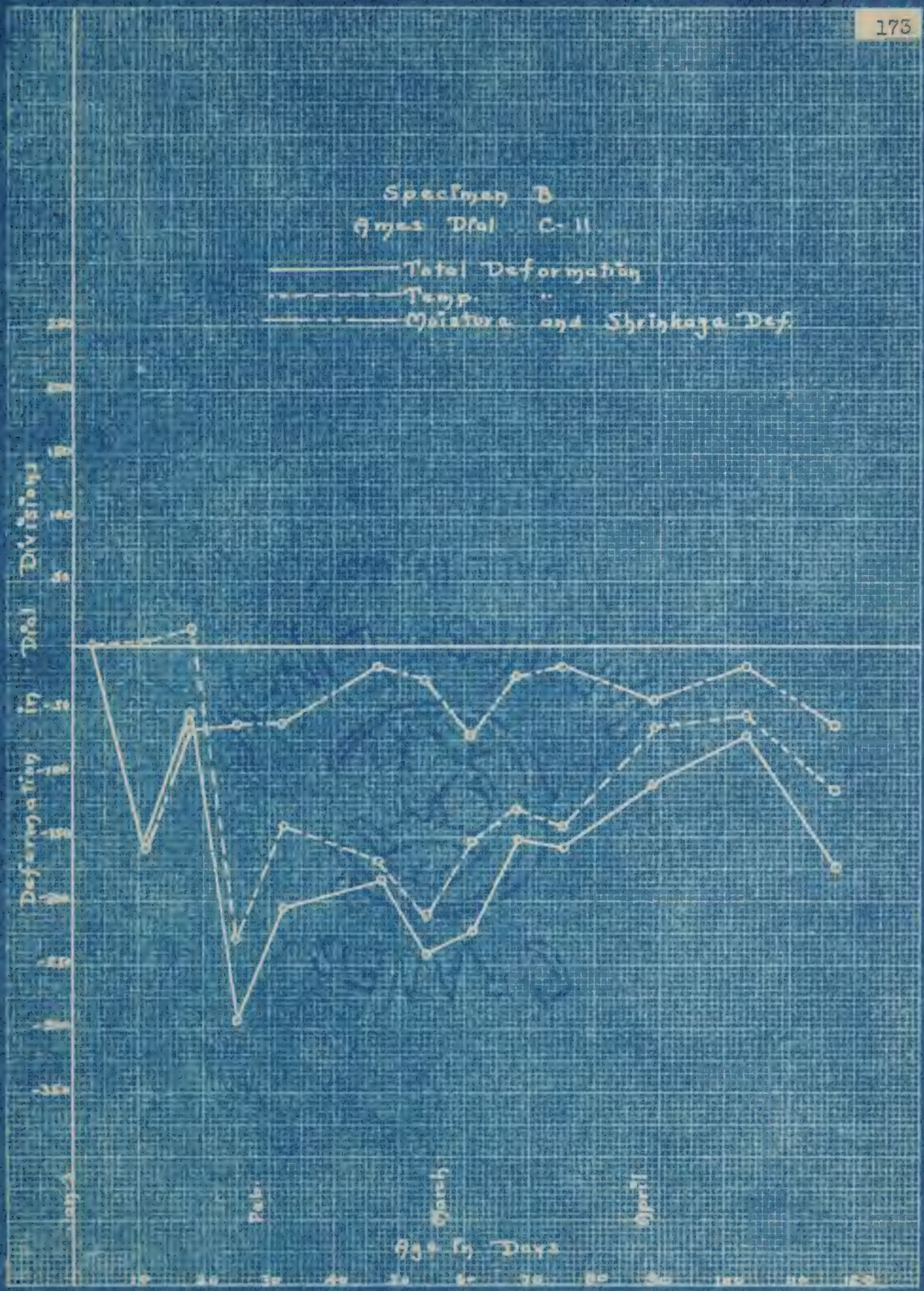

Specimen B
Ames Dial C-1
Total Deformation
Temp "
Moisture and Shrinkage Def
(Plug Reset)
Deformation
Age in Days


Specimen B
Ames Dial C-3
Total Deformation
Moisture and Shrinkage Def.
Deformations in Dial Divisions
Age in Days


Specimen B
Amsler Dial C-5
Total Deformation
Temp.
Moisture
Shrinkage Data
Total Deformation in Divisions
Deflection in Divisions
Feb.
March
April
Age in Days


Specimen B
Ames Dial C-7
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Deformations in Dial Divisions
Jan.
Feb.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120


Specimen B
Ames Dial C-9
Total Deformation
Temp. "
Moisture and Shrinkage Def
Deformations in Dial Divisions
Feb.
March
April
Age in Days


Specimen B
Ages Dial C-11
Total Deformation
Temp. "
Moisture and Shrinkage Def.
Deformation in Total Divisions
Age in Days
Feb.
March
April

Specimen 9
G. L. Top - Steel
T1
T3
T4
T6
Dec 23
Jan.
Feb.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

Specimen 9
G. L's Bottom - Steel
B1
B3
B4
B6
Dec 23
Jan
Feb
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120
Dof in Strain Gauge Divisions
+40
+10
0
-30
-20
-70
-60
-100
-90
-130
-90
-120

Specimen 9
G.L.: Top — Conc.
T1
T2
T3
T4
T5
Dec. 23
Jan.
Feb.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

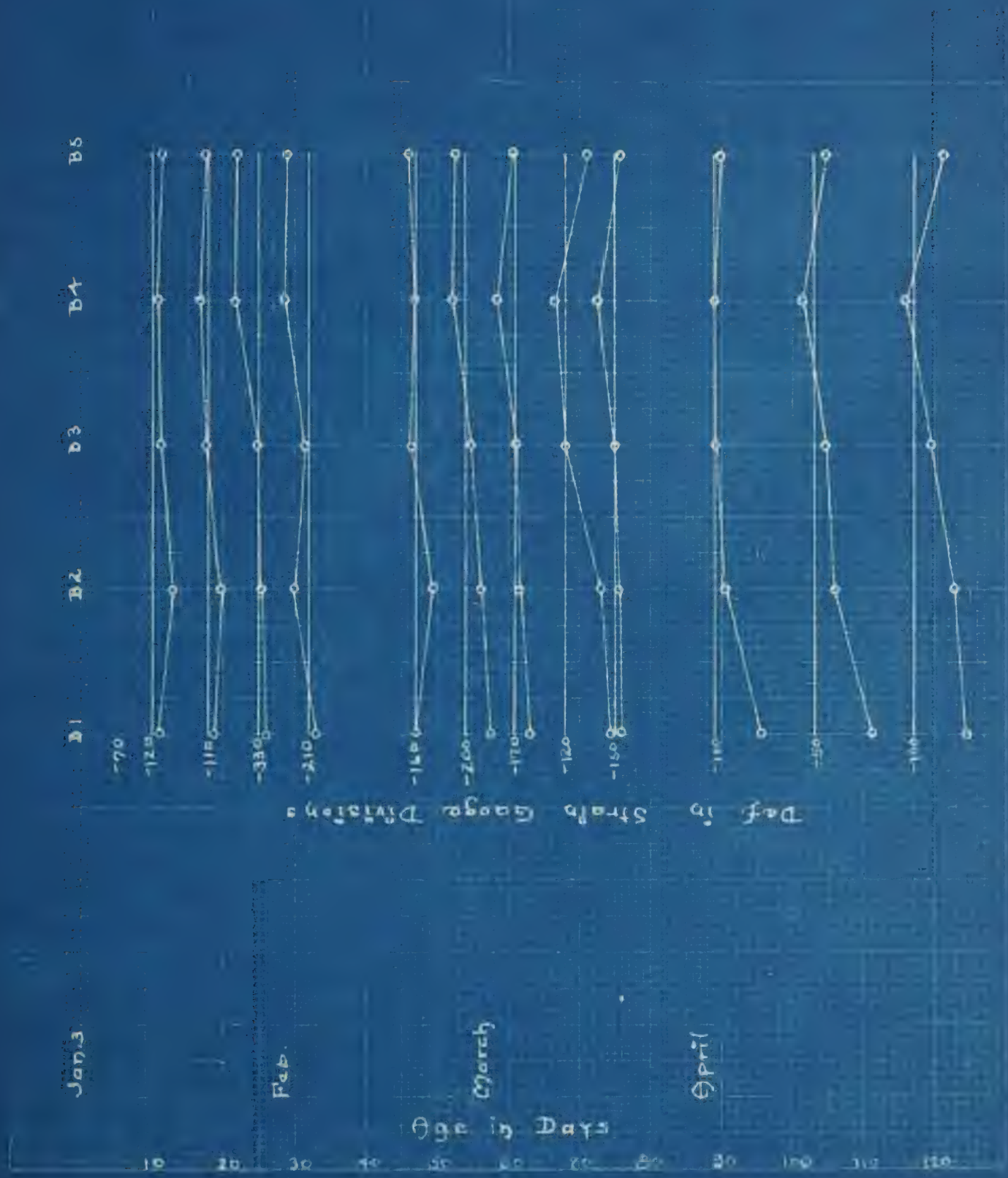
Specimen 9
G. W.'s Bottom - Conc.

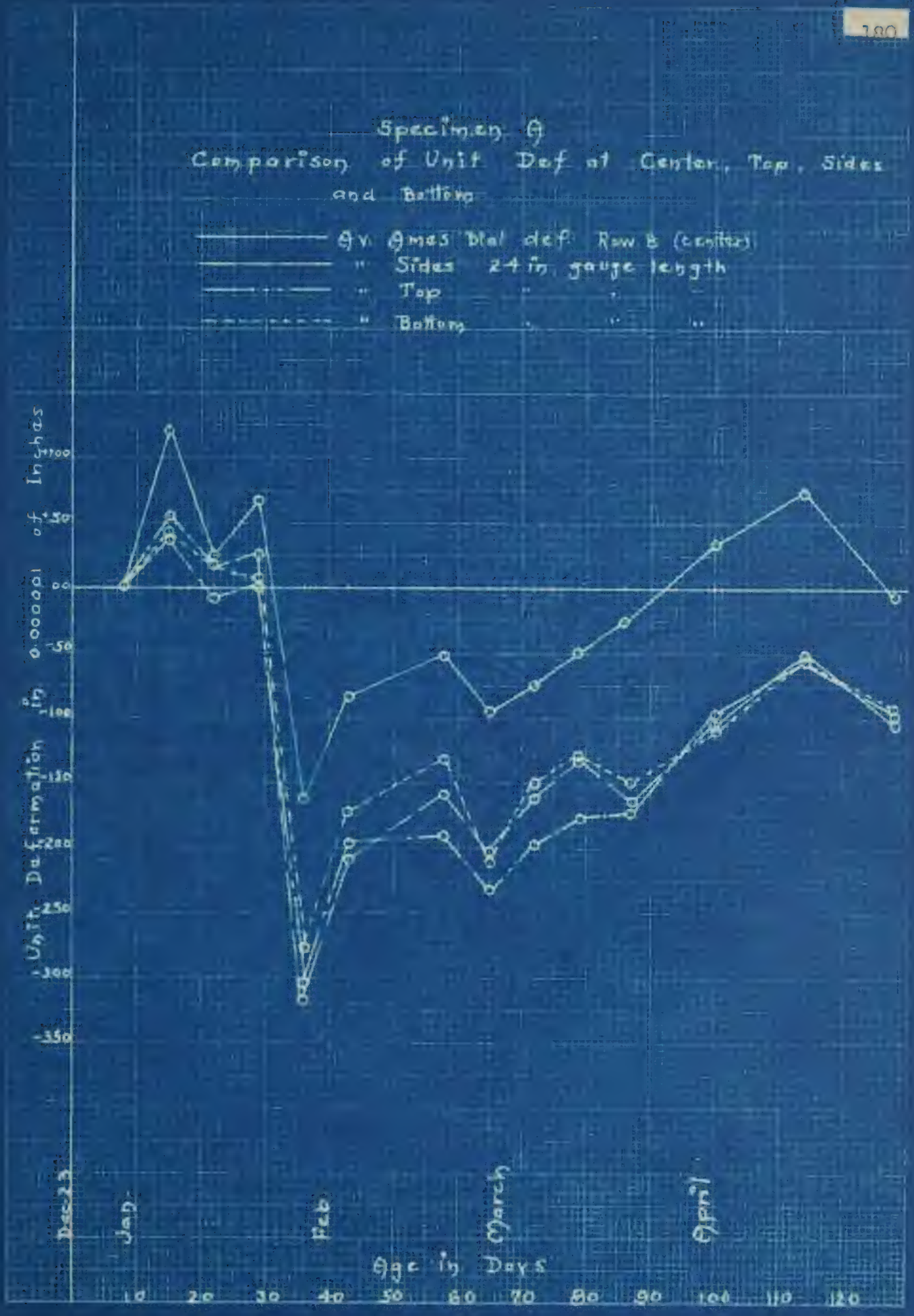
Dof in Strain Gauge Divisions

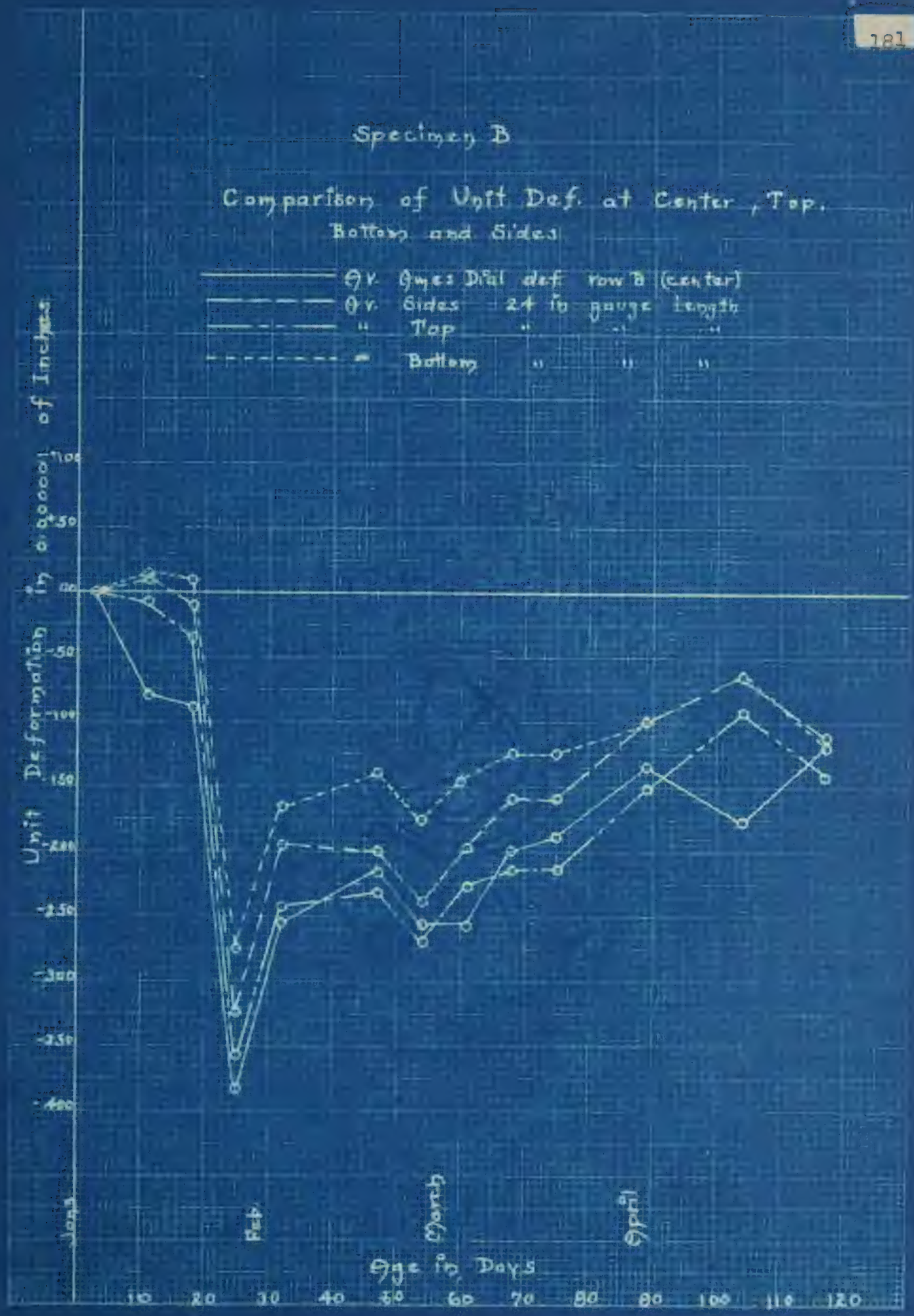
Specimen B
G.W.'s Top - Conc.
T1
T2
T3
T4
T5
Def. in Strain Gauge Divisions
Age in Days
Jan.
Feb.
March
April

Specimen B

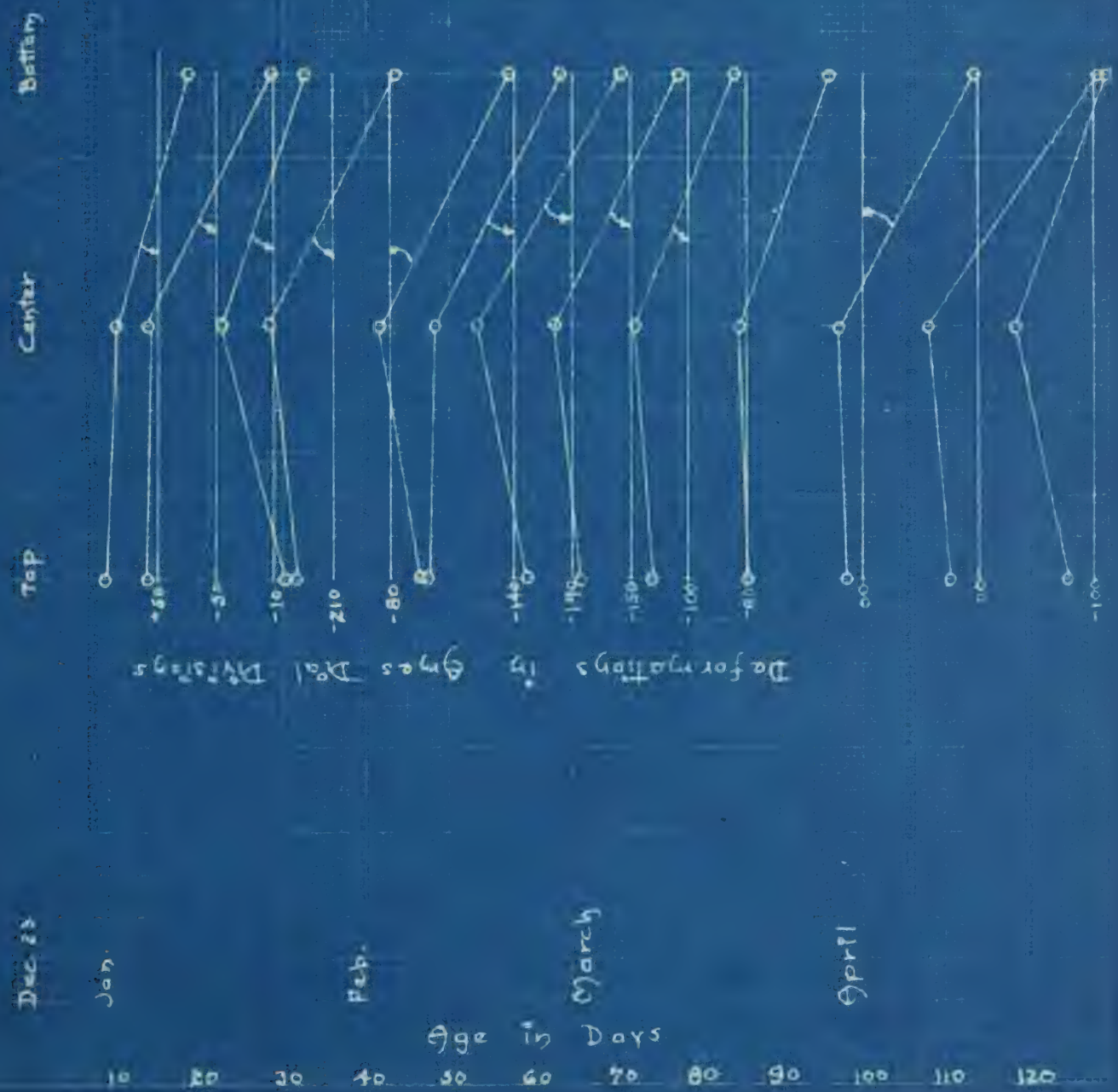
G. W's Bottom – Conc.



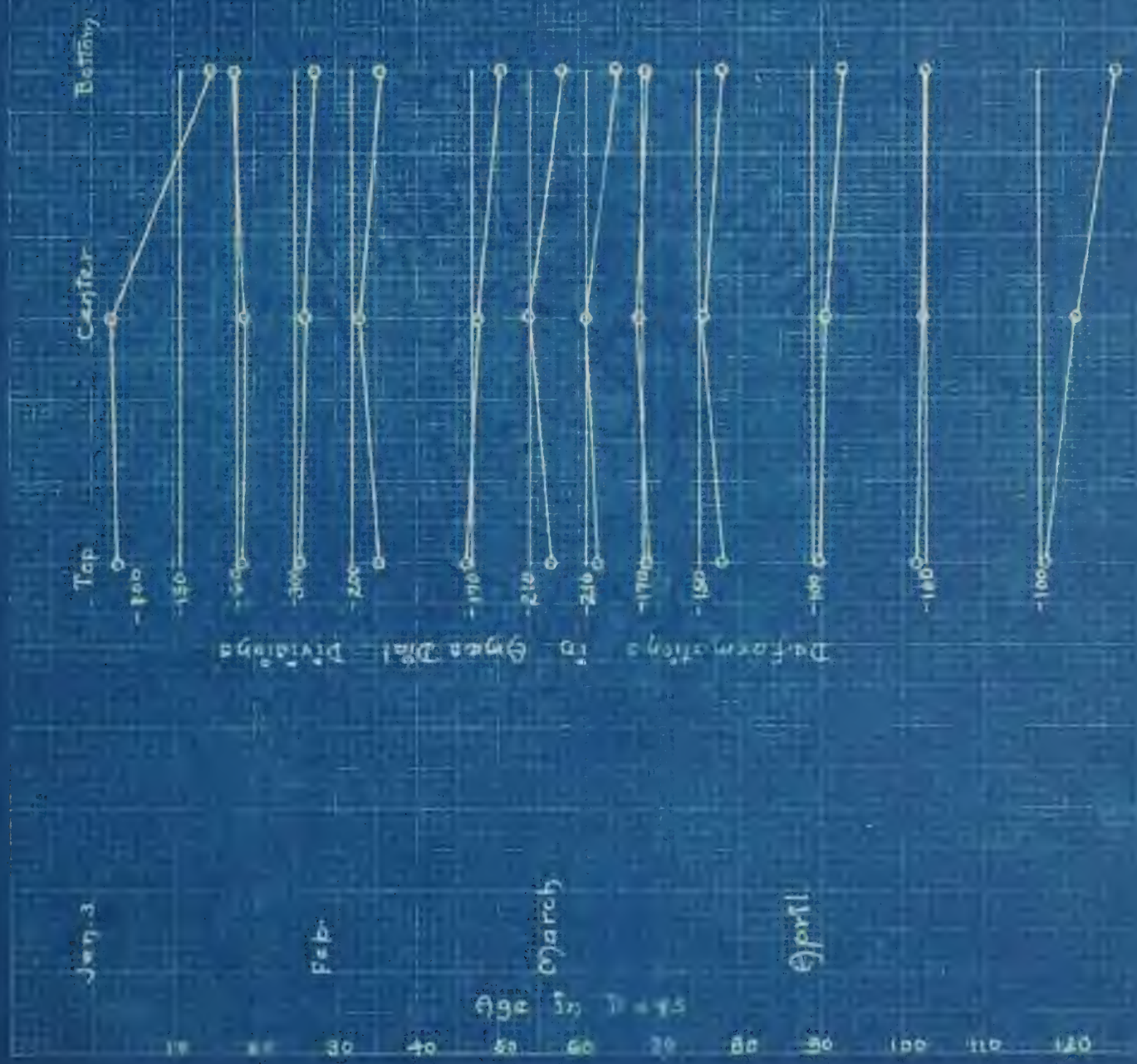

Specimen A
Comparison of Unit Def at Center, Top, Sides and Bottom
Av. Ames Dial def. Row B (center)
" Sides 24 in. gauge length
" Top " "
" Bottom " " "
Unit Deformation in 0.000001 of Inches
+100
+50
00
-50
-100
-150
-200
-250
-300
-350
Dec 23
Jan.
Feb
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120


Specimen B
Comparison of Unit Def. at Center, Top, Bottom and Sides
Q.V. Gages Dial def. row B (center)
Q.V. Sides 24 in gauge length
" Top " " "
" Bottom " " "
Unit Deformation in 0.00001 of Inches
+1.00
+.50
.00
-.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
Feb
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

Specimen A
Ames Dial
Av. Readings for Top, Center and Bottom



Specimen B
Ames Dial
Av. Readings for Top, Center and Bottom



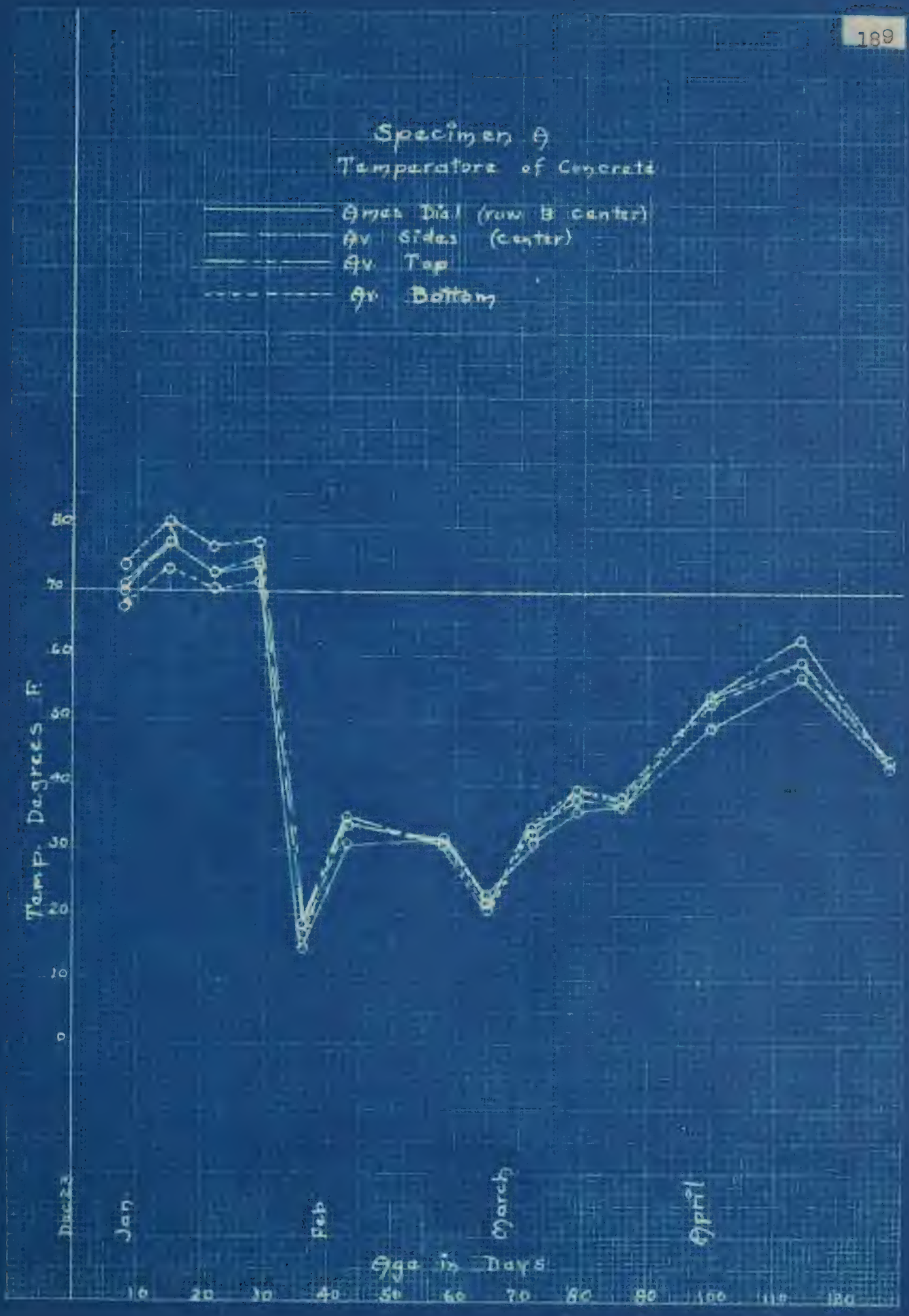
Specimen 8
Ames Dial
Row 8 = Top

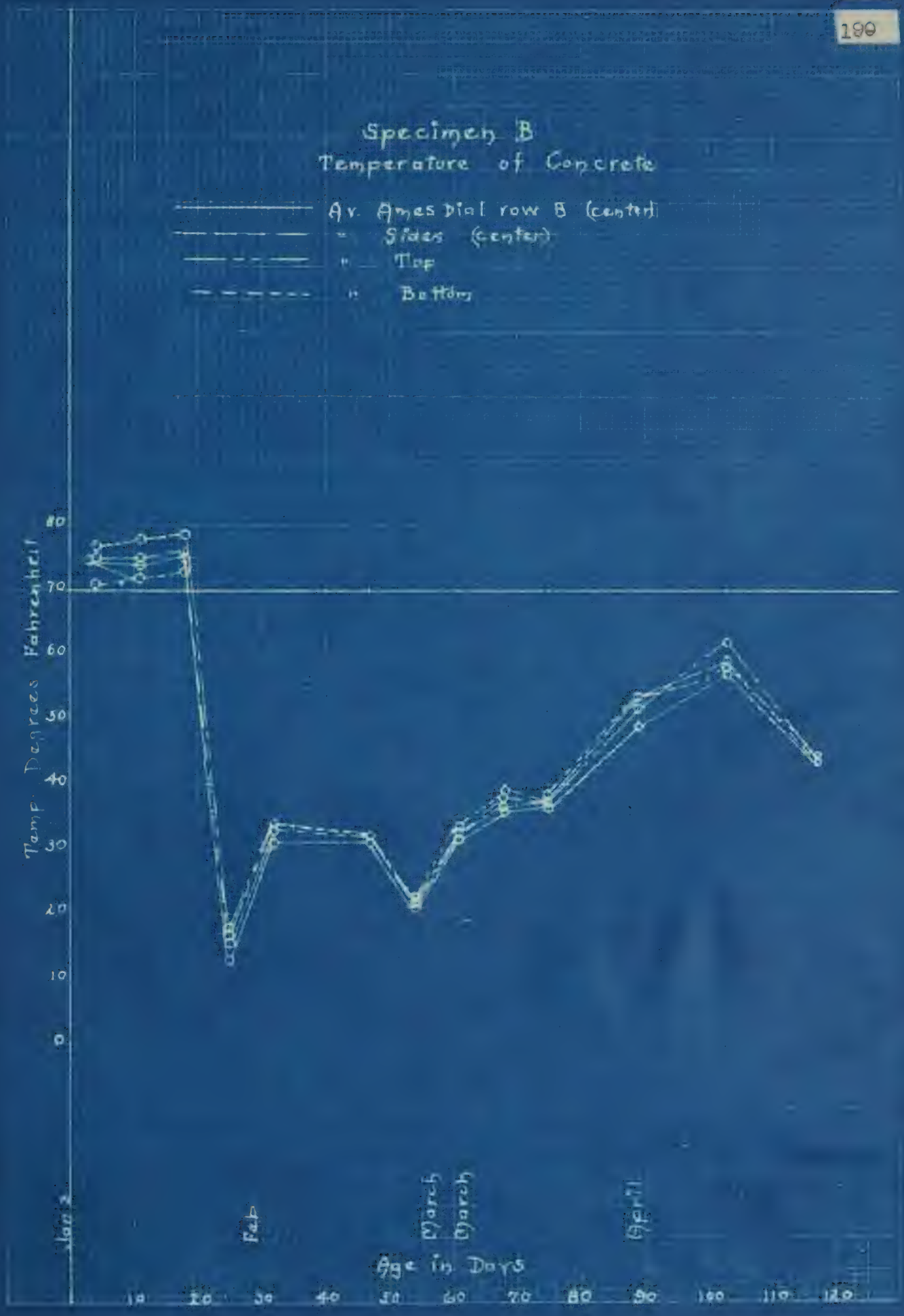
Specimen 9
Ames Dial
Row B Center
Ames Dial Points — Concrete
1
3
5
7
9
11
Deformations in Ames Dial Divisions
+100
+80
+60
+40
+20
-20
-40
-60
-80
-100
-120
+60
Dec. 23
Jan.
Feb.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

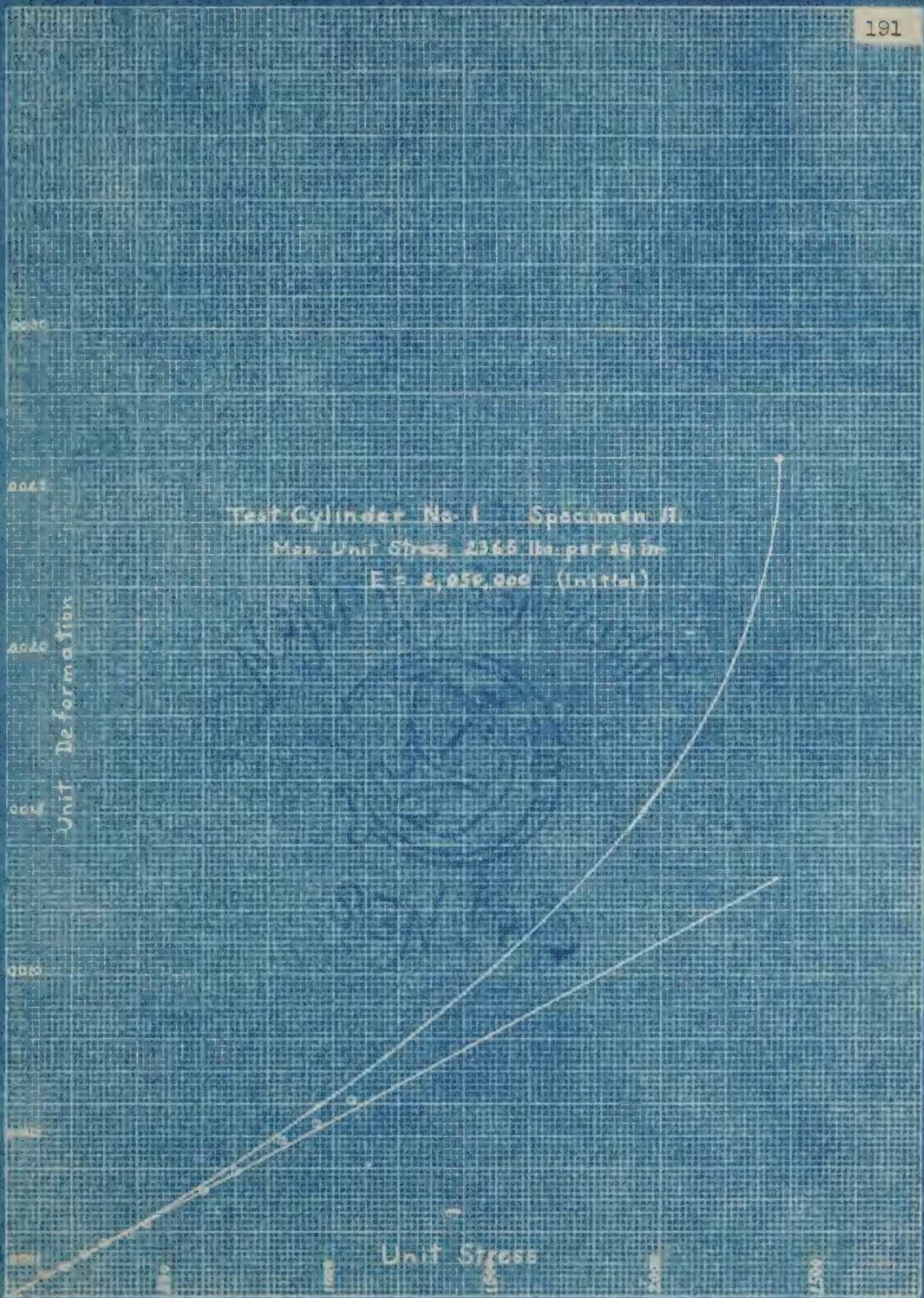
Specimen
Ames Dial
Row C Bottom

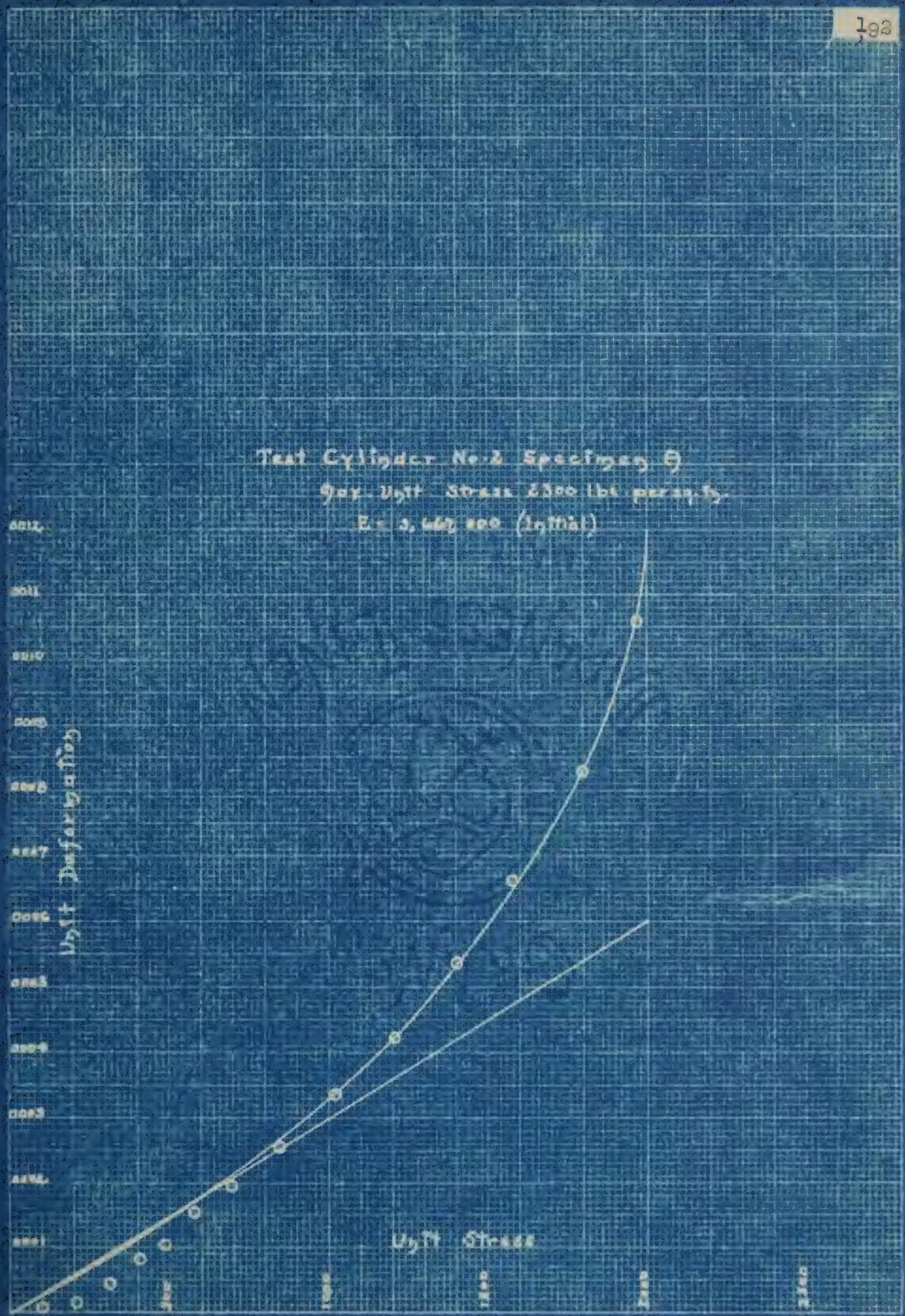
Specimen B
Ames Dial
Row 9 - Top
Ames Dial Points
1
3
5
7
9
11
Initial Rdg
-700
-390
-300
-240
-170
-220
-220
-160
-160
-80
80
-100
Total Deformation in Ames Dial Divisions
Jan.3
Feb.
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

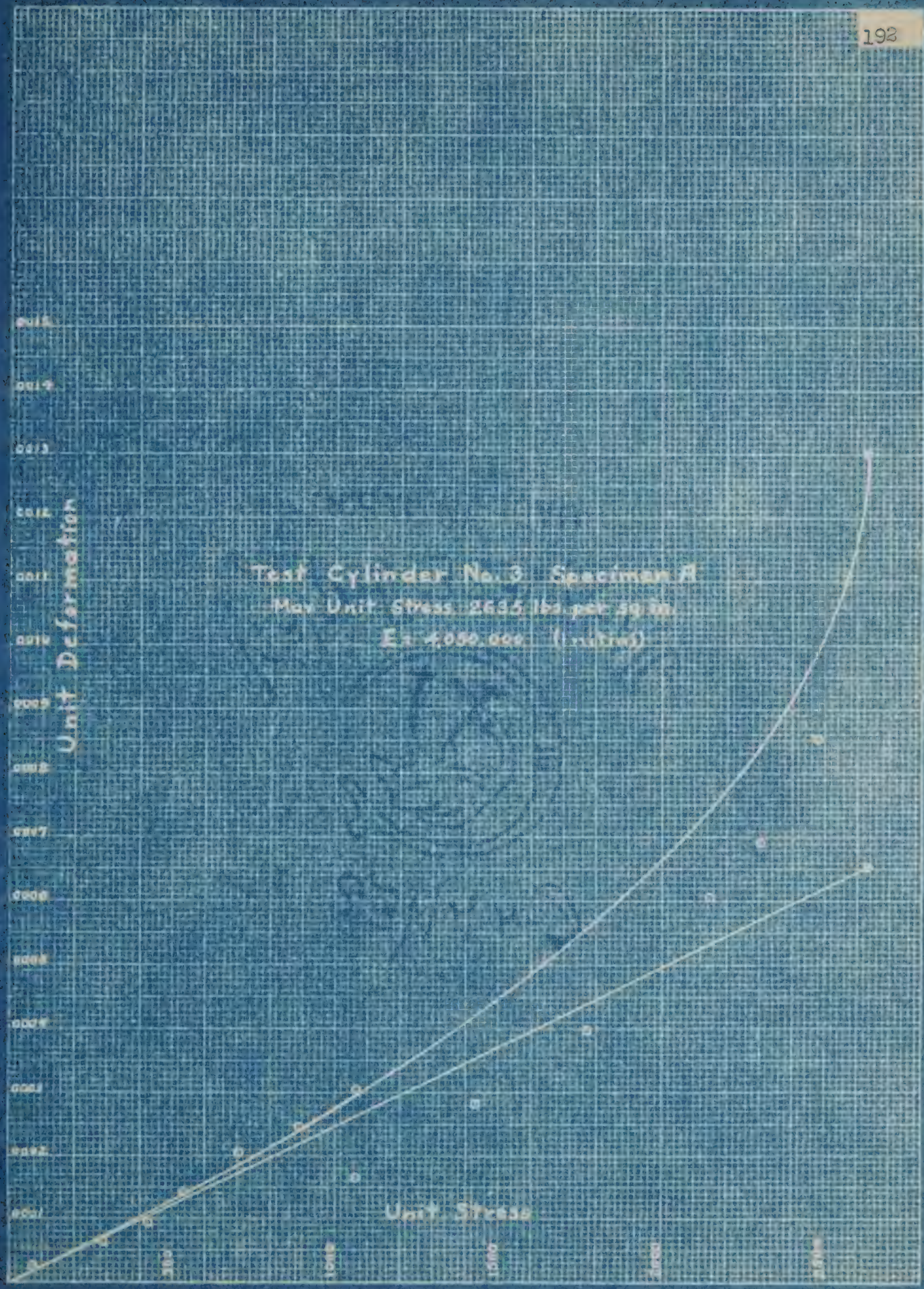
Specimen B
Ames Dial
Row B - Center
Ames Dial Points
Initial Rdg.
Total Deformation in Ames Dial Divisions
Age in Days
Jan 3
Feb
March
April

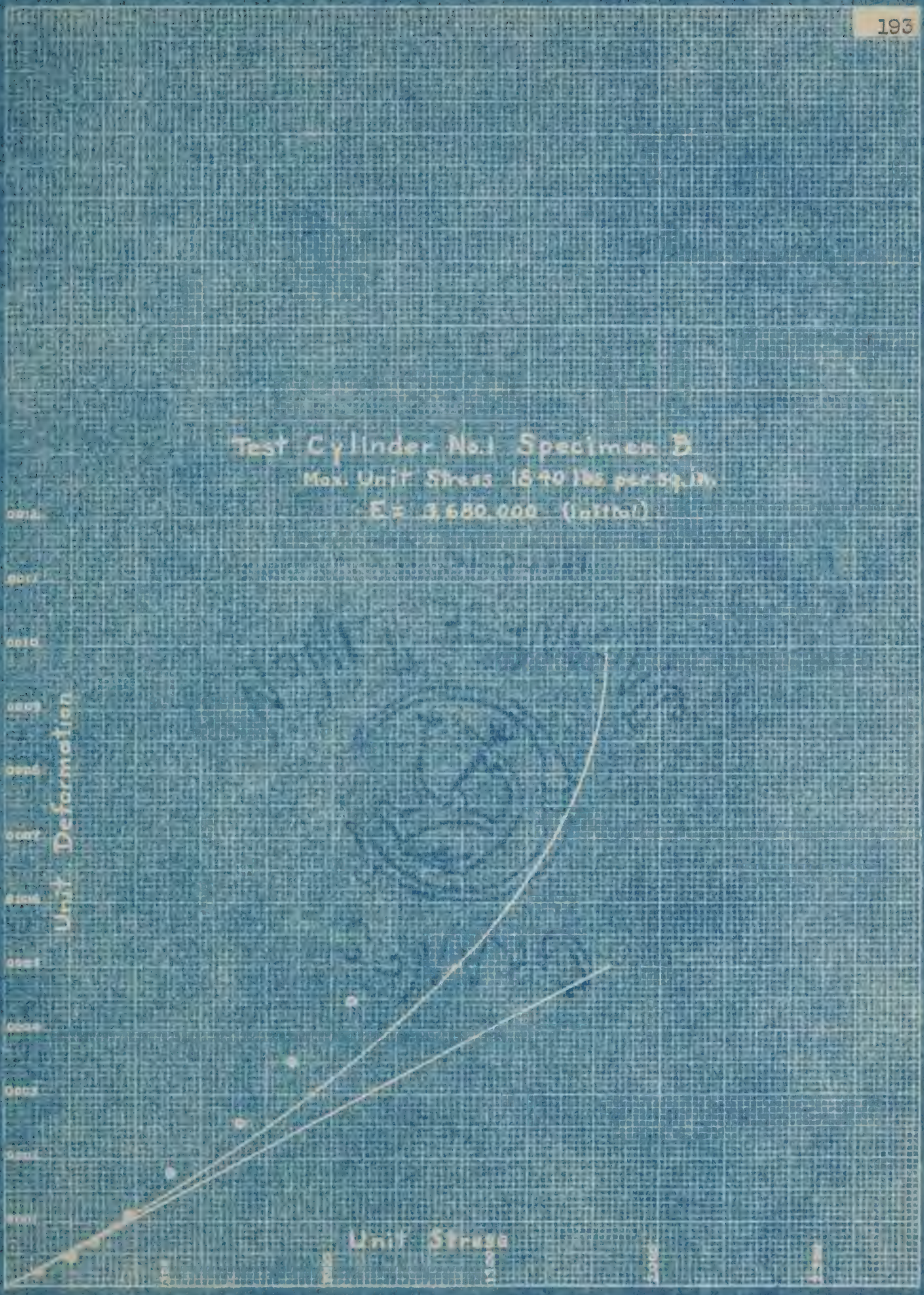

Specimen A
Temperature of Concrete
Amer Dial (row B center)
Av Sides (center)
Av Top
Av Bottom
Temp. Degrees F.
80
70
60
50
40
30
20
10
0
Dec 23
Jan
Feb
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

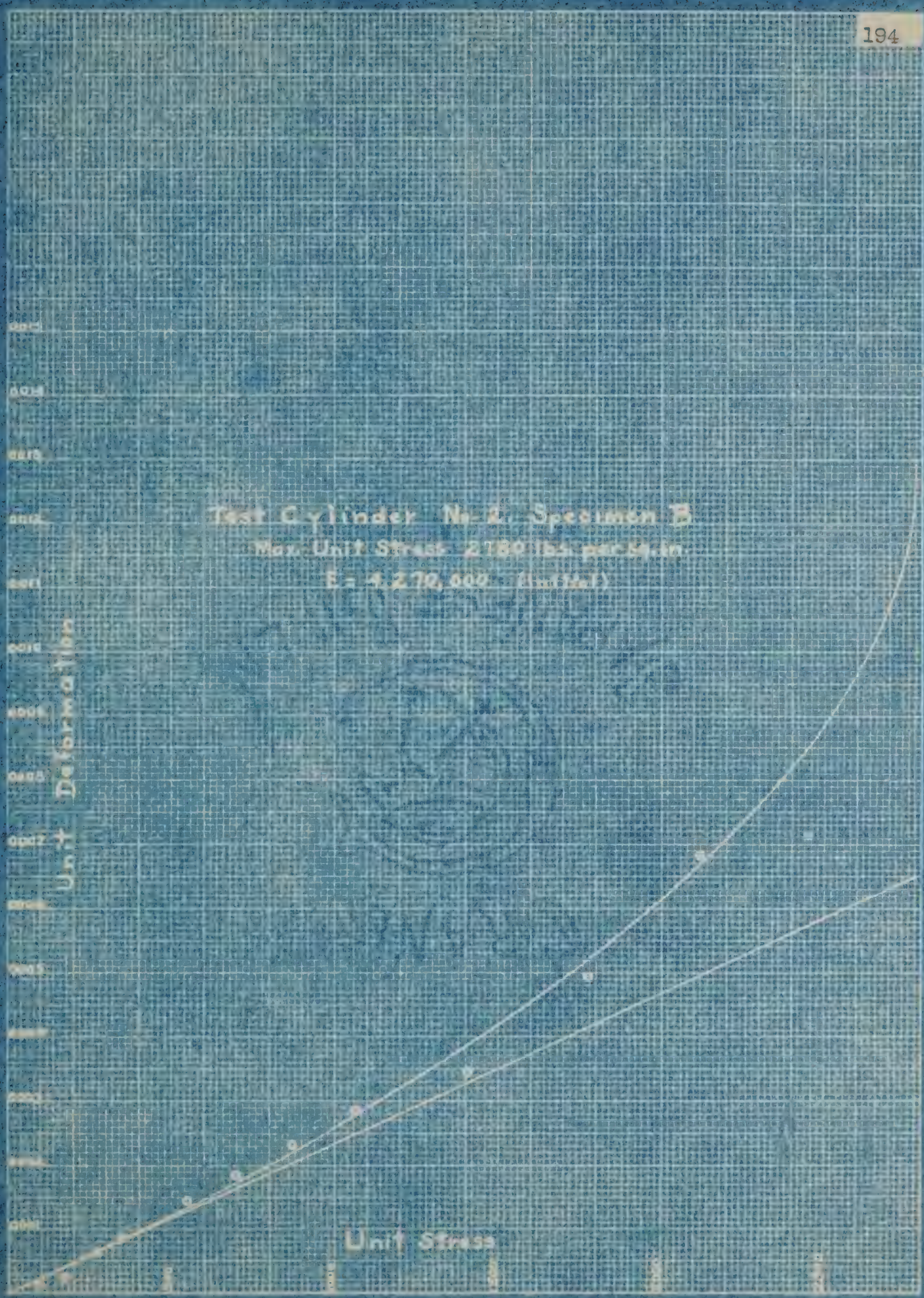

Specimen B
Temperature of Concrete
Av. Ames Dial row B (center)
" Sides (center)
" Top
" Bottom
Temp. Degrees Fahrenheit
80
70
60
50
40
30
20
10
0
Jan 2
Feb
March
March
April
Age in Days
10
20
30
40
50
60
70
80
90
100
110
120

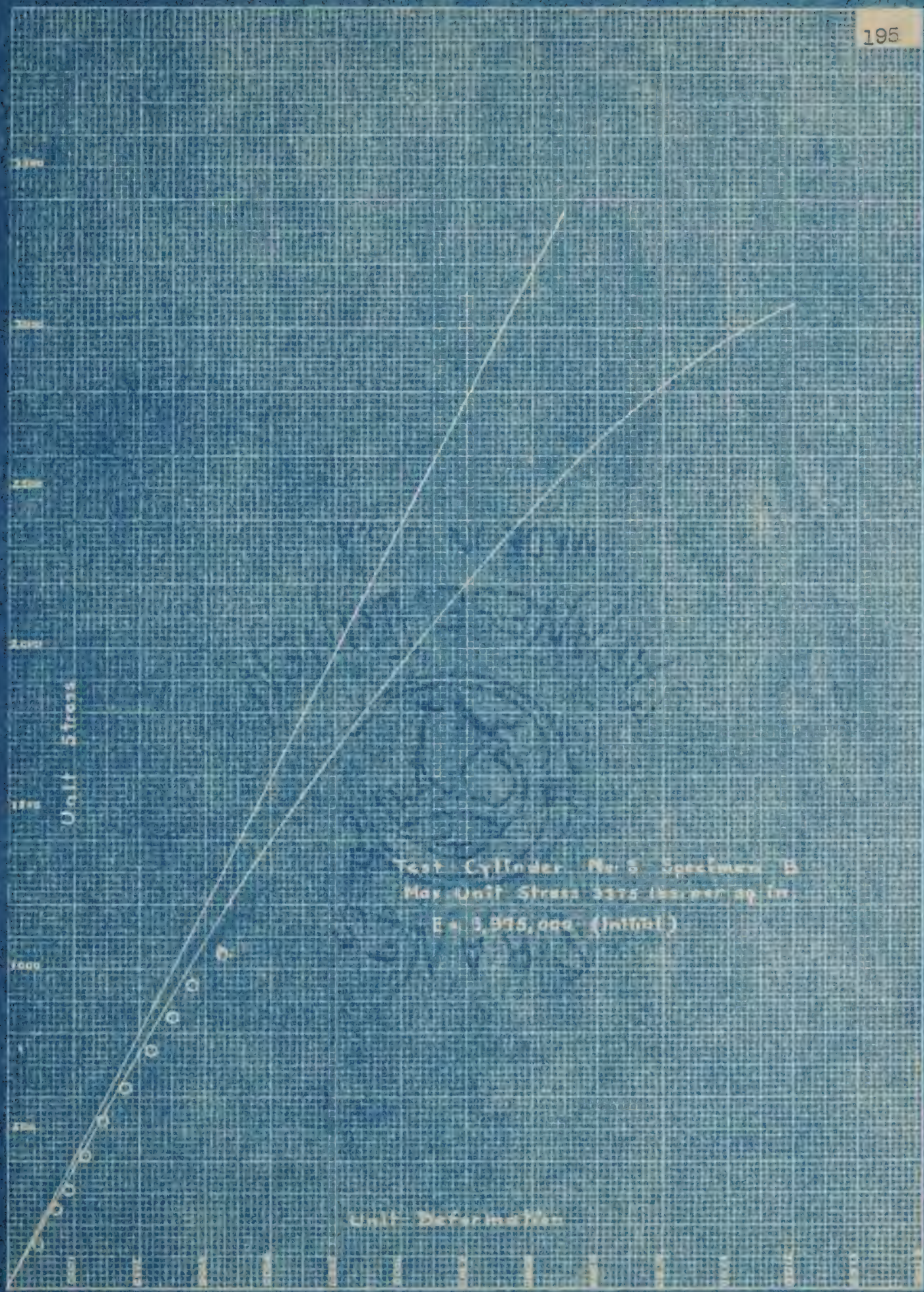

Test Cylinder No. 1 Specimen A
Max. Unit Stress 2366 lbs. per sq. in.
E = 6,050,000 (initial)
Unit Deformation
Unit Stress


Test Cylinder No. 2 Specimen 9
Unit Stress
Unit Deformation


Test Cylinder No. 3 Specimen A
Max Unit Stress 2695 lbs per sq in
E = 4,000,000 (initial)
Unit Deformation
Unit Stress
.0015
.0014
.0013
.0012
.0011
.0010
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.0001
0
500
1000
1500
2000
2500
3000


Test Cylinder No.1 Specimen B
Max. Unit Stress 1840 lbs. per sq. in.
E = 3,680,000 (initial)
Unit Deformation
Unit Stress


Test Cylinder No. 1, Specimen B
Max. Unit Stress 2780 lbs. per sq. in.
E = 4,270,000 (Initial)
Unit Deformation
Unit Stress


Unit Stress
Test Cylinder No. 5 Specimen B
Max Unit Stress 3375 lbs. per sq in.
E = 3,995,000 (initial)
Unit Deformation

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